The progress of FengYun series satellite data assimilation at CMA

Zhang Hua, Li Juan, Liu Guiqing，Gong Jiandong，
Han Wei,Ma Gong, Xu Jianmin and Zhang Qishong

China Meteorological Administration（CMA）

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Outline

- FengYun series satellite
- Analysis & Forecast Model: GRAPES
- FY-3/MWTS radiances assimilation
- FY-2 AMV assimilation
- Summary

国家气象中心
NATIONAL METEOROLOGICAL CENTER

1. FengYun series satellite

Capacity of Chinese Meteorological Satellite

Since Jan. 1969, China began to develop his own meteorological Satellite

Leo	Launch Data		Geo	Launch Data
FY-1A	Sept. 7, 1988		FY-2A	Jun. 10, 1997
FY-1B	Sept. 3, 1990		FY-2B	Jun. 25, 2000
FY-1C	May 10, 1999		FY-2C	Oct. 18, 2004
FY-1D	May 15, 2002		FY-2D	Dec. 8, 2006
FY-3A	May 27, 2008			

国家气象中心
NATIONAL METEOROLOGICAL CENTER

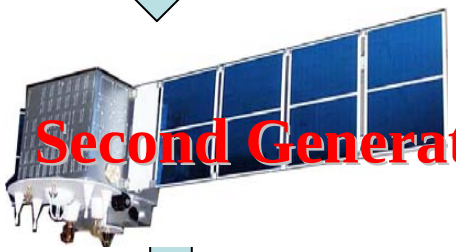
Chinese Meteorological Satellite: FengYun Series

Polar System

FY
|
1A
1B
1C
1D

First Generation

FY
|
3A
3B
3C
↓
3H



Second Generation

Geostationary System

First Generation

FY
|
2A
2B
2C
2D
2E

Second Generation

FY
|
4

Payloads onboard on FY-3A

Abbreviation	*Instrument Full Name*
VIRR	Visible and InfraRed Radiometer
IRAS	InfraRed Atmospheric Sounder
MWTS	MicroWave Temperature Sounder
MWHS	MicroWave Humidity Sounder
MERSI	MEdium Resolution Spectral Imager
SBUS	Solar Backscatter Ultraviolet Sounder
TOU	Total Ozone Unit
MWRI	Microwave Radiation Imager
SIM	Solar Irradiation Monitor
ERM	Earth Radiation Measurement
SEM	Space Environment Monitor

Basic Information for Each Instrument

Name of Instrument	Number of Channels	Spectral range	Field of Views /line	Spatial Resoluation at Sub point (km)
VIRR	10	0.43 – 12.5μm	2048	1.1
IRAS	26	0.69 – 15.5 μm	56	17
MWTS	4	50 – 57 GHz	15	50/75
MWHS	5	150 – 183 GHz	90	15
MERSI	20	0.41 – 12.5 μm	2048/8192	1.1/250
SBUS	12	252 – 380 nm	240	70/10
TOU	6	309 – 361 nm	31	50
MWRI	6	10.65 – 150 GHz	240	15-70

Outline

- FengYun series satellite
- Analysis & Forecast Model: GRAPES
- FY-3/MWTS radiances assimilation
- FY-2 AMV assimilation
- Summary

国家气象中心
NATIONAL METEOROLOGICAL CENTER

2. Analysis & Forecast Model: GRAPES

Main features of GRAPES-3DVar

Grid analysis	A+P with flexible resolution setup	
incremental	$x_a = x_b + \delta x$	
Variable options	analysis	Φ/T, u, v, rh
	control	ψ, χ , Φ_u , rh
preconditioning	control space $\Rightarrow$ model space	$\delta x = Uw$, $U \Leftrightarrow U_p U_v U_h$
	Regional : Recursive filter	for U_h
	Global : Spectral filter	for U_h
Minimization	Limited memory BFGS method	
Mass-wind constraint	Linear balance equation (now) Nonlinear balance equation (on testing)	
Programming	Fortran90, Modular structure, to be paralleled	

Main features of GRAPES dynamics

- Fully compressible equations
- Height-based terrain-following coordinate
- Switch between Hydrostatic and Non-hydrostatic
- Arakawa C lat-lon horizontal grid

  Charney-Phillips vertical grid
- 2-time-level semi-implicit semi-Lagrangian (SISL) time-stepping
- QMSL for scalar advection
- GCR for Helmholtz Eq.
- 3D vector form of SISL formulation
- Spherical & polar effects of trajectory calculation
- Cascade interpolation
- Mass fixer
- Polar filter
- 4^{th} order horizontal diffusion

Special for Global version

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Physics

- ✓ Cumulus: Betts-Miller
- ✓ Grid-scale precipitation: NCEP cloud-3
- ✓ Radiation: ECMWF or GFDL radiation package
- ✓ PBL: non-local pbl
- ✓ Land surface: SLAB
- ✓ Cloud: ECMWF diagnostic method

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Data application of GRAPES-3DVAR

✓ *ATOVS microwave* (NOAA15 16 17)	radiances
✓ FY-3/Metop/NOAA-18/AIRS	radiance
✓ Sondes	geop/ humidity / wind
✓ Synops	geop/ humidity/ wind
✓ Ships	geop/ humidity/ wind
✓ Airep	temp/ wind
✓ Satob	wind
✓ GPS	reflectivity

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Outline

- FengYun series satellite
- Analysis & Forecast Model: GRAPES
- FY-3/MWTS radiances assimilation
- FY-2 AMV assimilation
- Summary

国家气象中心
NATIONAL METEOROLOGICAL CENTER

3. FY-3/MWTS radiances assimilation

Key technique

The cost function :

$$J = \frac{1}{2}(x - x^b)^T B^{-1}(x - x^b) + \frac{1}{2}(Hx - y^o)^T R^{-1}(Hx - y^o)$$

Observation operater

Observation error

Basic hypothesis

$E(\varepsilon^b) = 0,\ E(\varepsilon^o) = 0$ Gaussian

QC
Bias-correction
Cloud detection

$E(\varepsilon^b \varepsilon^{oT}) = 0$

$B = E(\varepsilon^b \varepsilon^{bT}),\quad R = E(\varepsilon^o \varepsilon^{oT})$ R is diagonal matrix

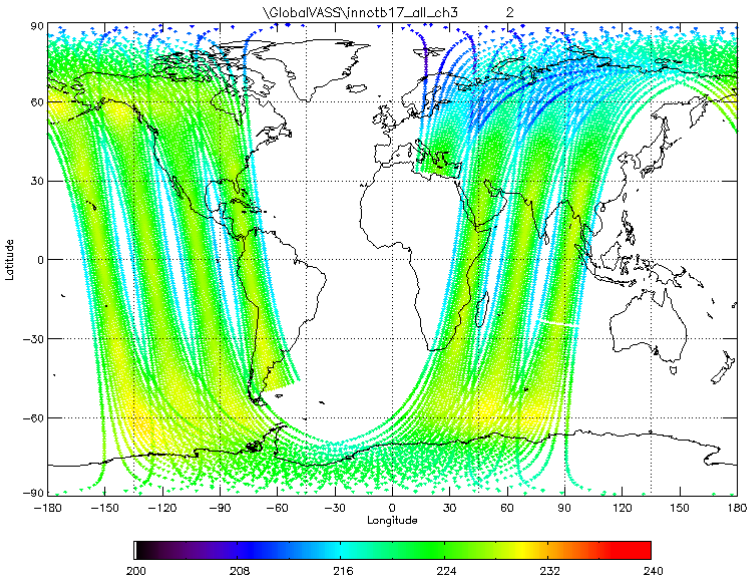
thinning

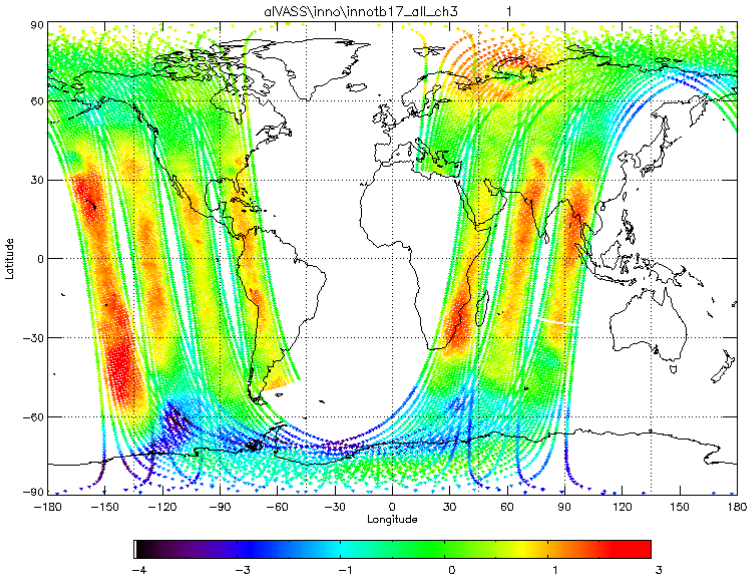
国家气象中心
NATIONAL METEOROLOGICAL CENTER

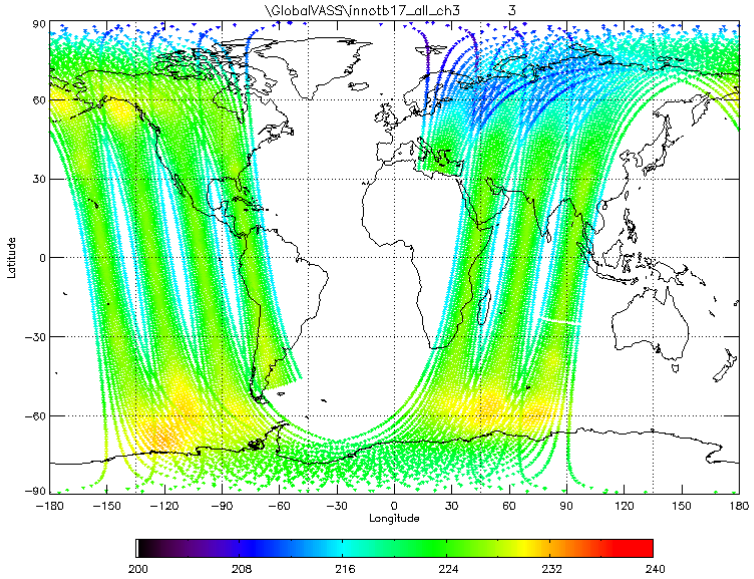
Verifying the observations & its Operater

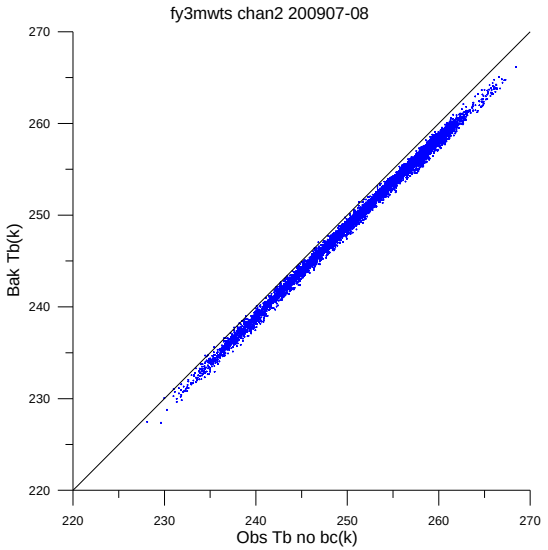
- The observational Operater : developed by NSMC on basis of the radiance transfer model RTTOV-7
- Background: 6 hour forecast
- FY-3/MWTS Ch1-4

FY3 MWTS CH3









simulation

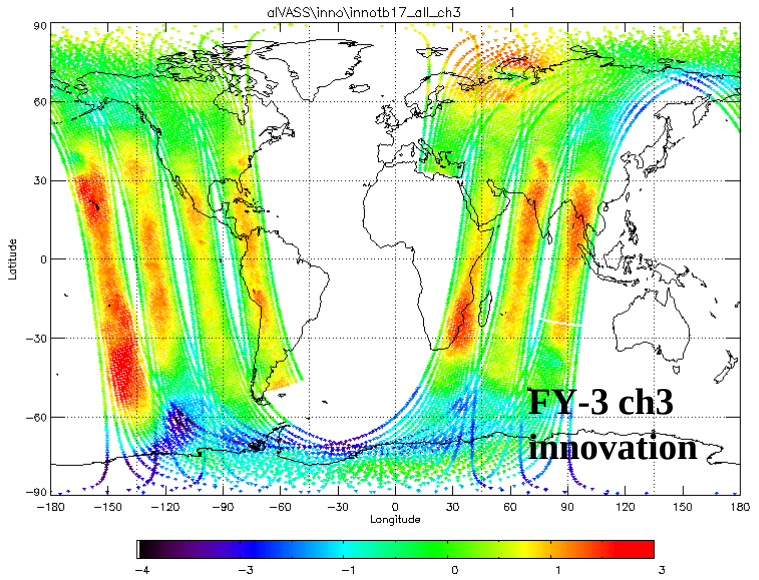
innovation

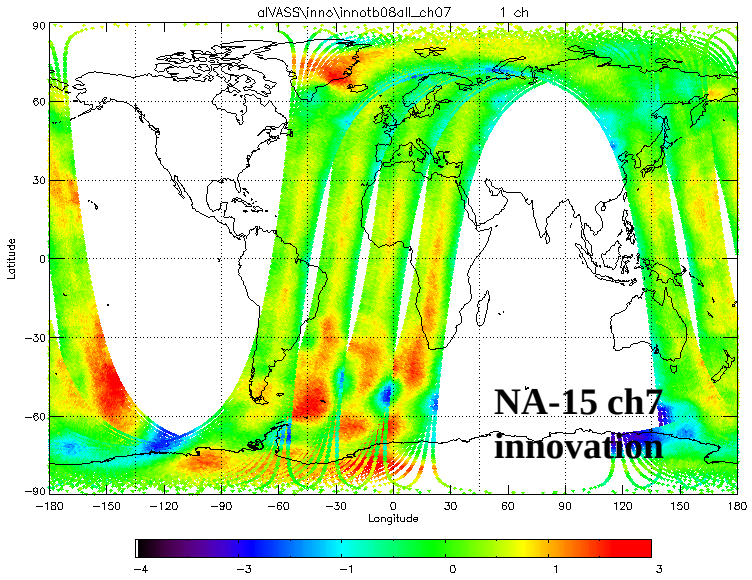
Obs.

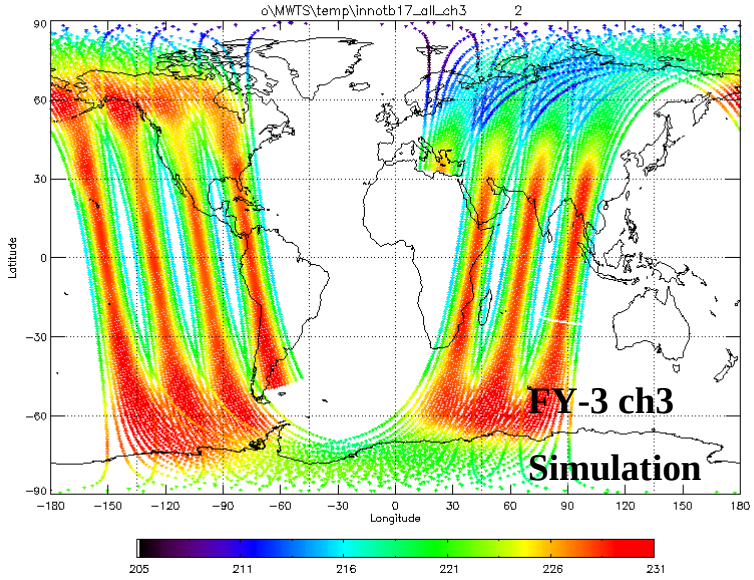
国家气象中心
NATIONAL METEOROLOGICAL CENTER

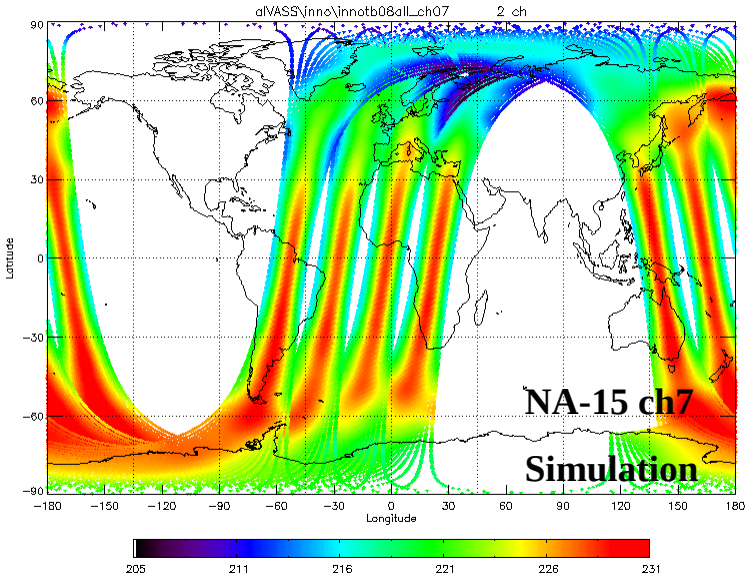
Comparing FY-3 ch3 with NOAA-15 ch7

(left : FY-3 right : NOAA-15 top : innovation bottom : simulated)









Bias correction

Harris&kelly方法（off-line）

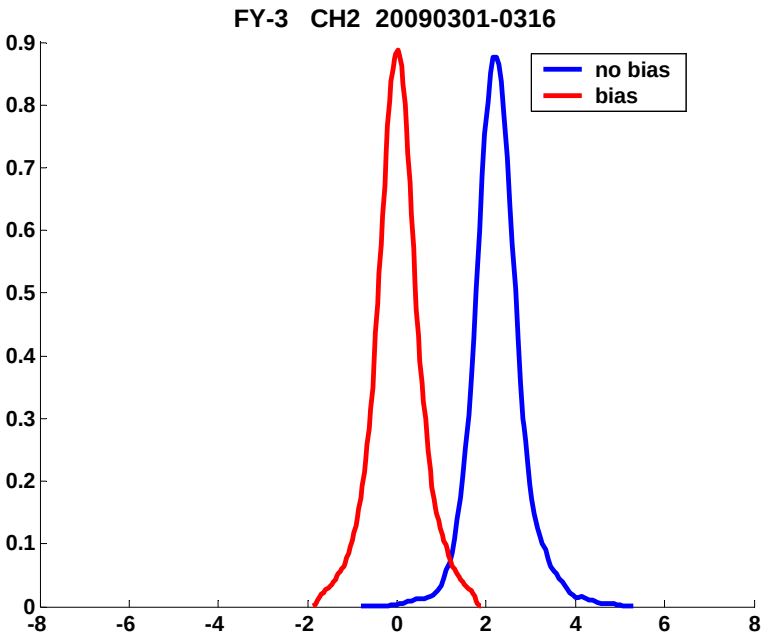
- scan correction
  - dependent on latitude
  - $s(\Phi,\theta) = R(\Phi,\theta) - R(\Phi,\theta = 0)$

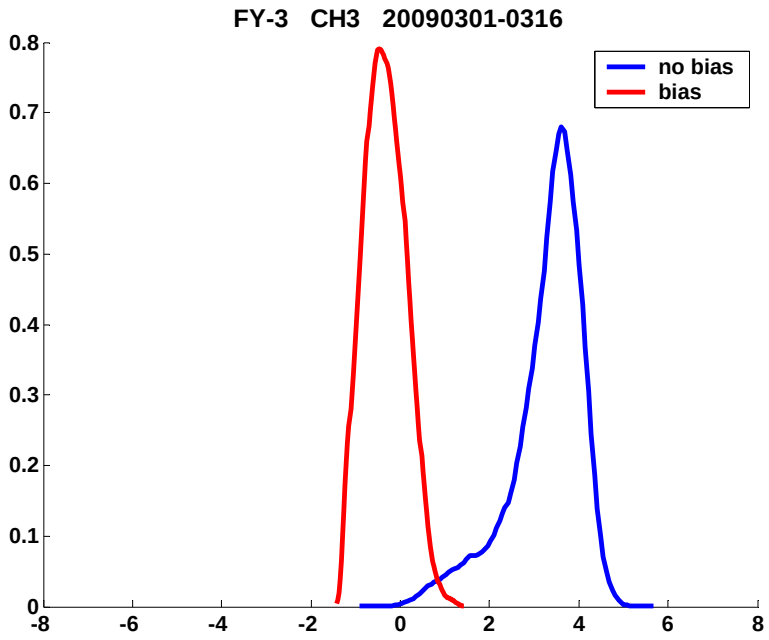
- air-mass correction
  - Harris&kelly方法

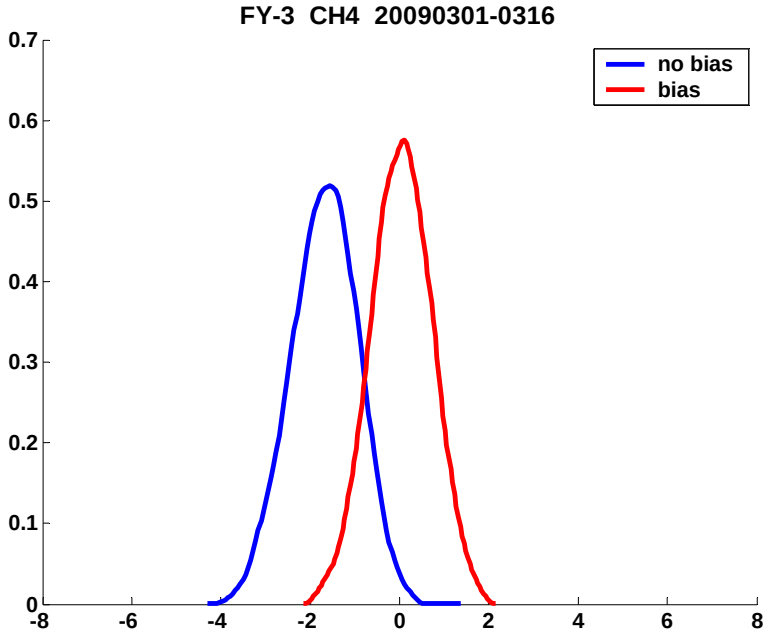
$$\mathrm{Bias}_j(\theta) = a_{j0} + \sum_{i=1}^{2} a_{ji}(\theta) X_{ji}(\theta)$$

  - 2 predictor

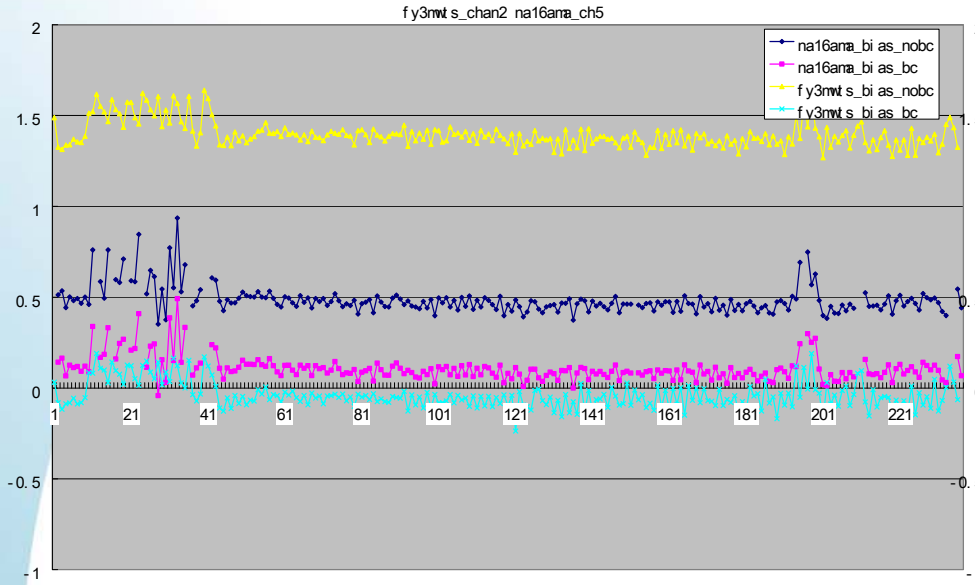
国家气象中心
NATIONAL METEOROLOGICAL CENTER

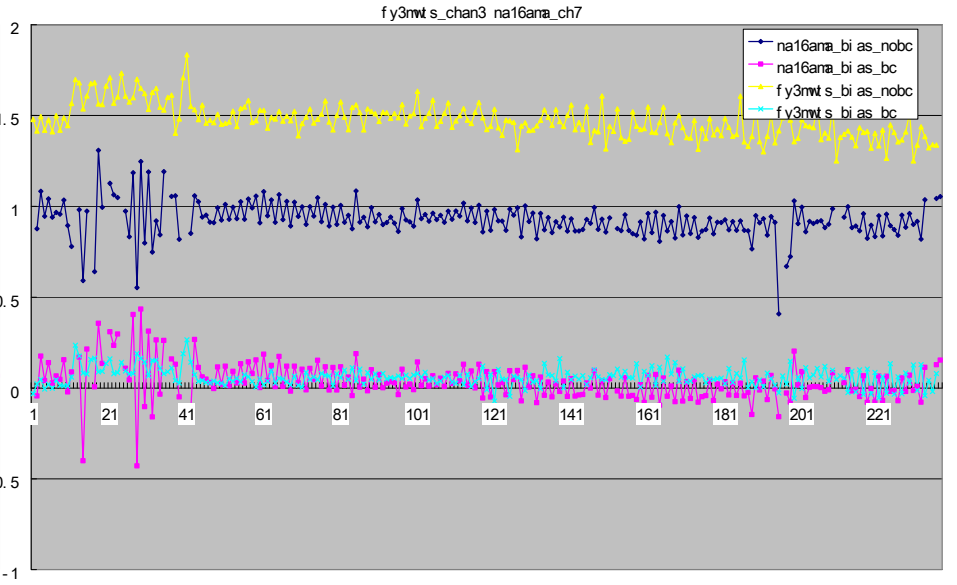


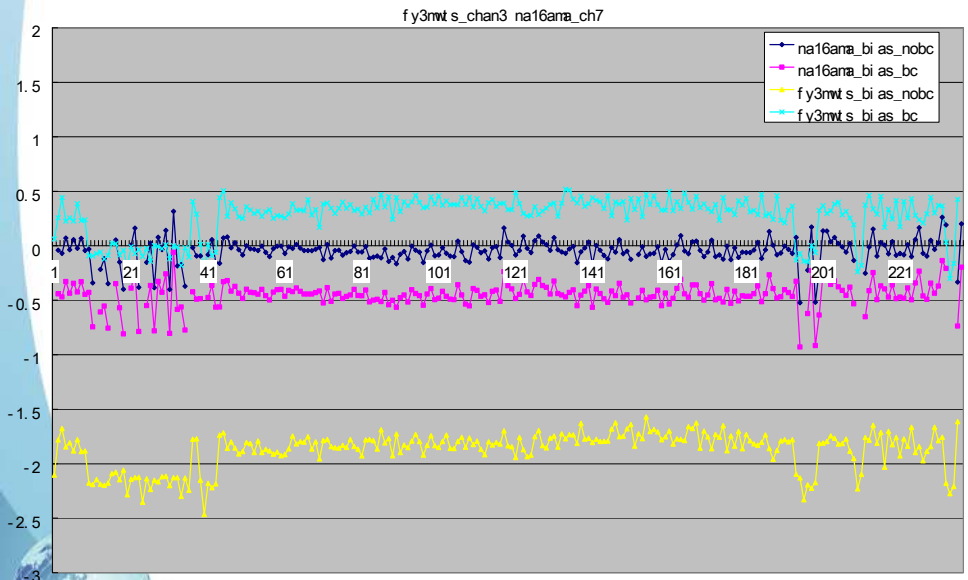




国家气象中心
NATIONAL METEOROLOGICAL CENTER



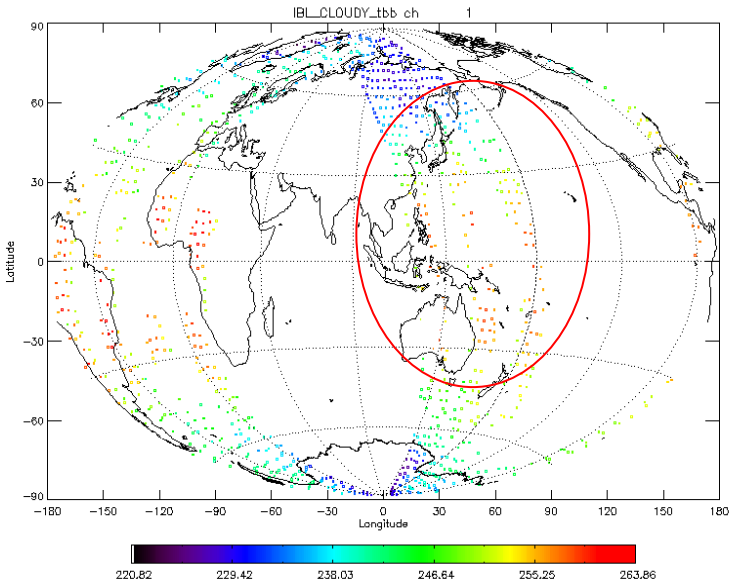




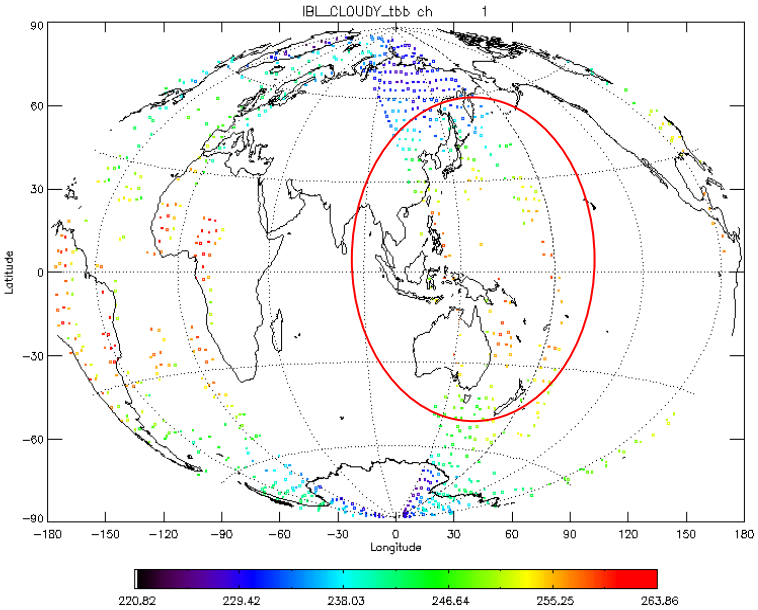
国家气象中心
NATIONAL METEOROLOGICAL CENTER

Cloud detection

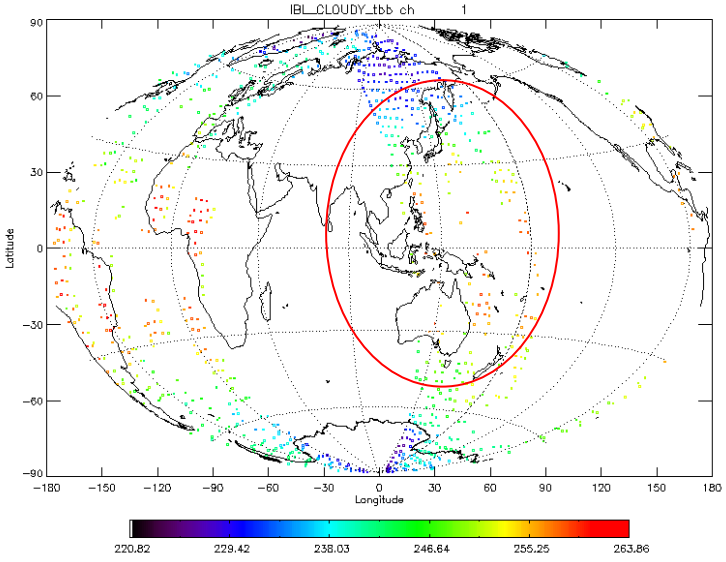
window chanl d-tbb >3k

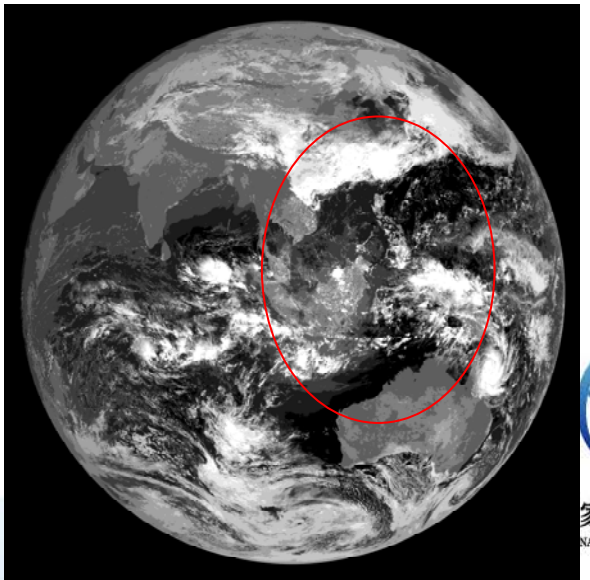


window chanl d-tbb >4k



window chanl d-tbb >3.5k √





家气象中心
NAL METEOROLOGICAL CENTER

Channel selection

Channel **Num**	**Frequency (MHz)**	**Chn width (MHz)**	**Majar asorption component**	**Height of peak contrabution**	Majar observation purpose
1	50,310	180	window	surface	Surface Emissivity
2	**53,596±115**	**170**	**O_2**	**700 hPa**	**Temperature**
3	**54,940**	**400**	**O_2**	**300 hPa**	**Temperature**
4	**57,290**	**330**	**O_2**	**90 hPa**	**Temperature**

国家气象中心
NATIONAL METEOROLOGICAL CENTER

General Quality Contral

- The extreme value check

✓350K ~150K

- Boundary check

✓2<scan position<14

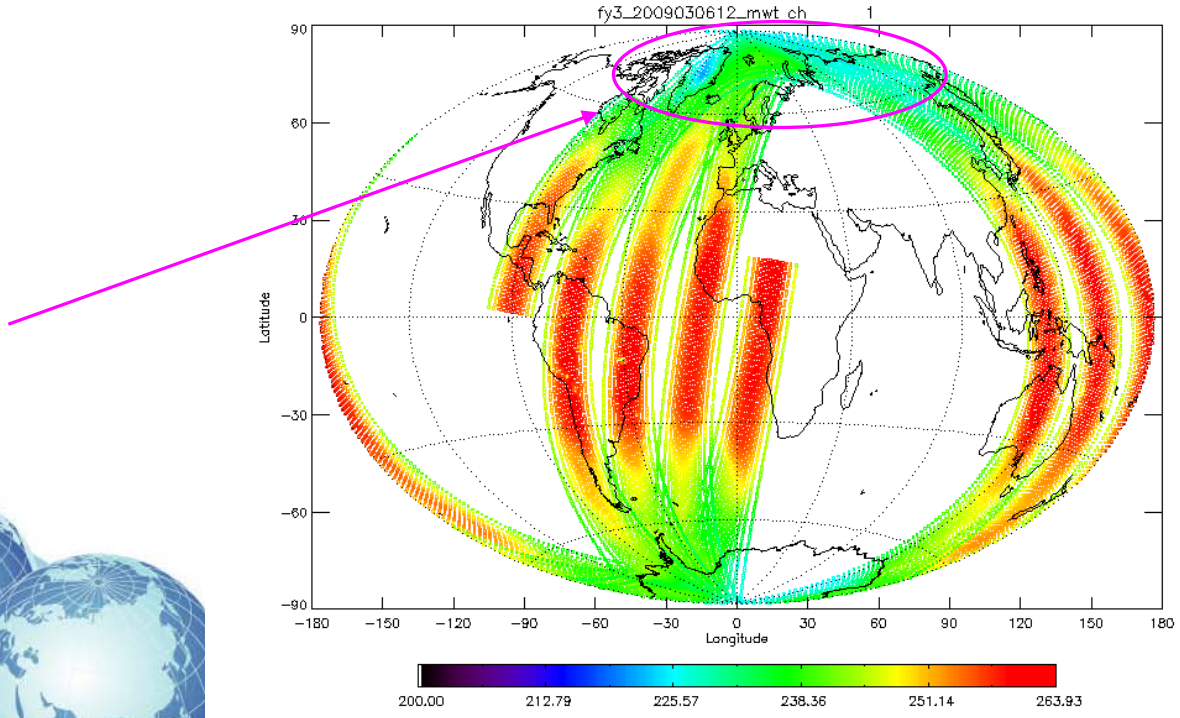
- Background check

✓ $\left|y(x_b) - y_o\right| \le n(\sigma_o + \sigma_b)$

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Thinning

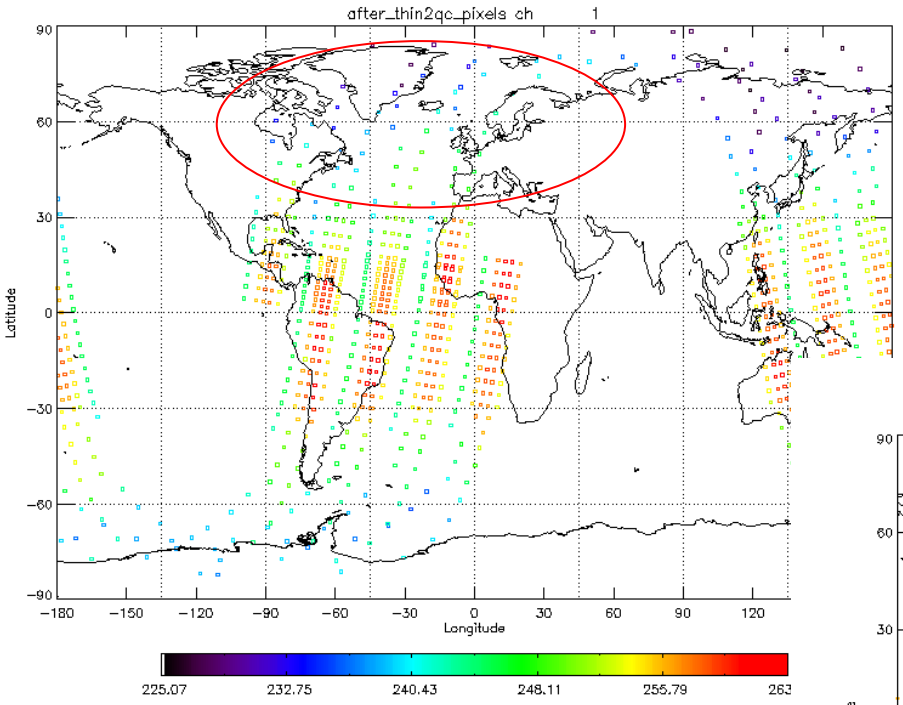
- In thining box (400km)
  - Select clear sky observations
  - Uniform distribution
  - As the track overlap, select the observations which close to analysis time.



国家气象中心
NATIONAL METEOROLOGICAL CENTER

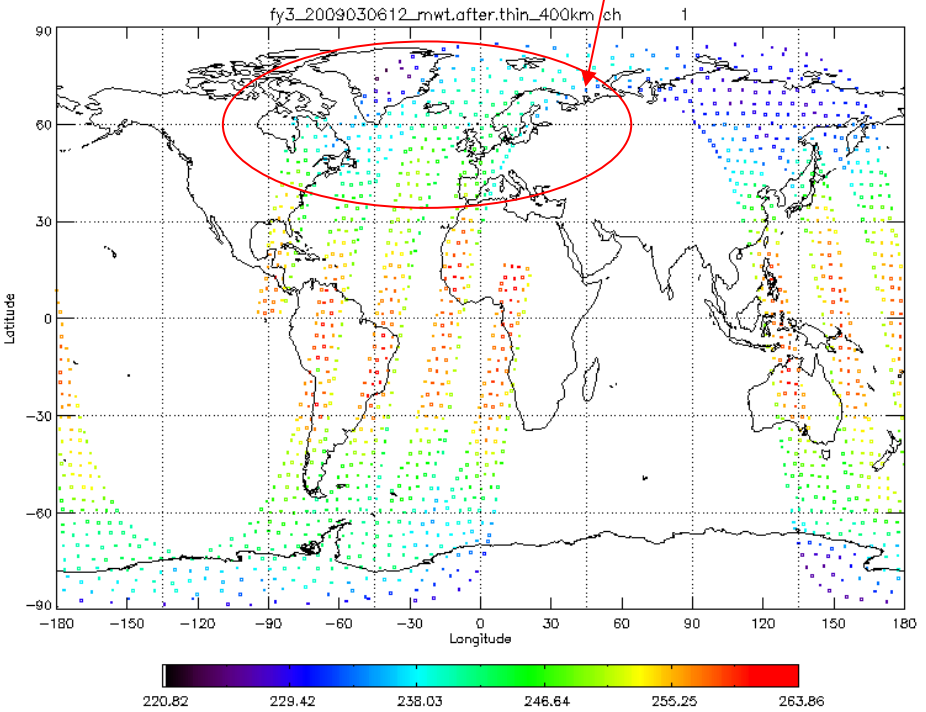
Thinning

old scheme



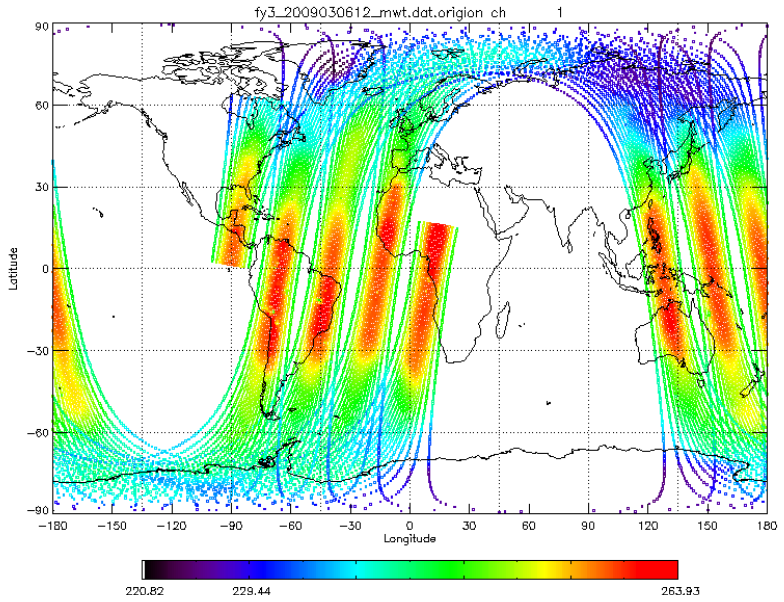
Select clear sky obs.
Uniform distribution
As the track overlap, select the observations which close to analysis time.

new scheme

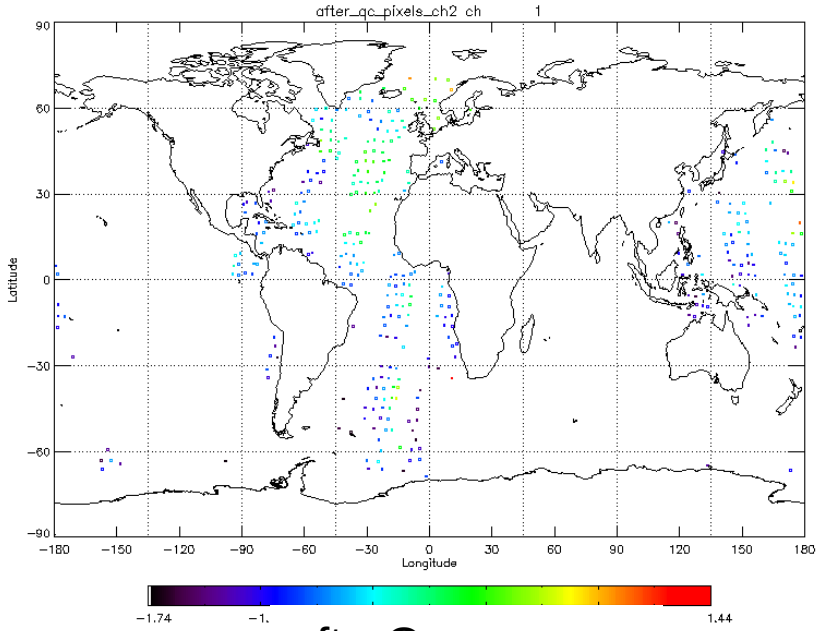


原始数据与质量控制后实际使用的数据分布 2009030612

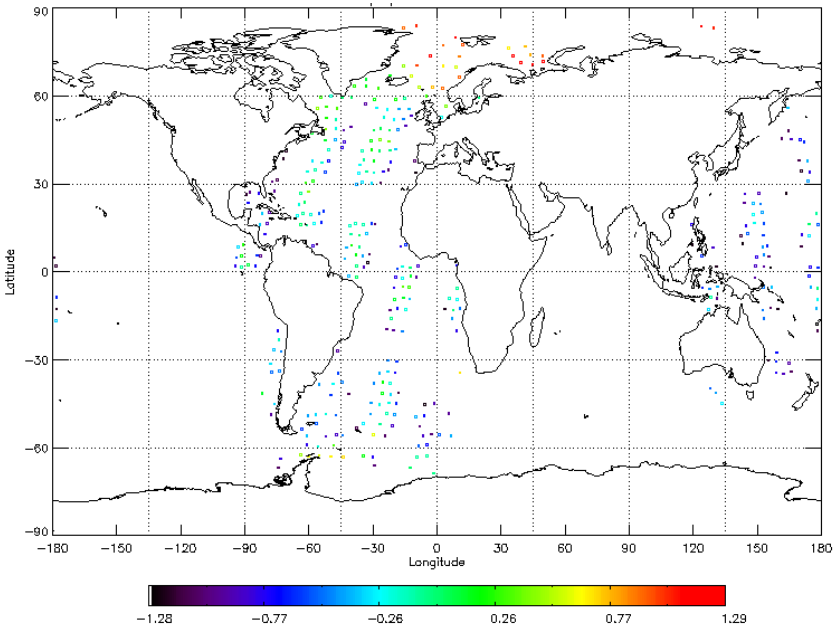
Origion



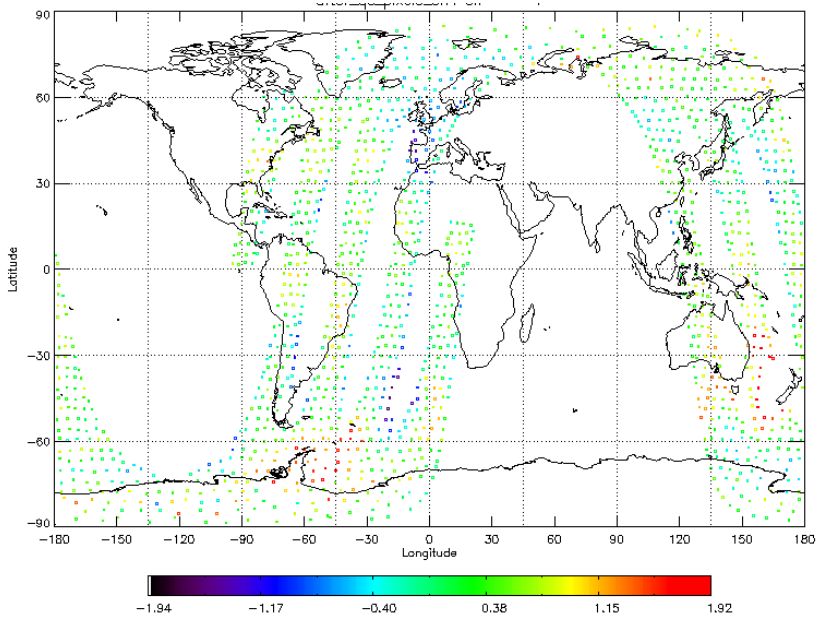
afterQc Channel 2



afterQc Channel 3



afterQc Channel 4



Forecast Impact experiments (1)

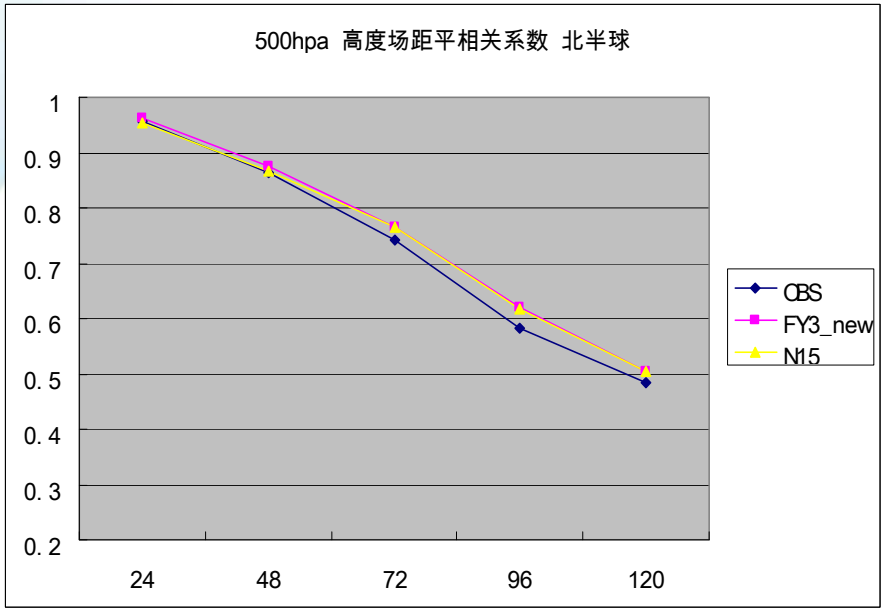
Date：1~20 Mar 2009

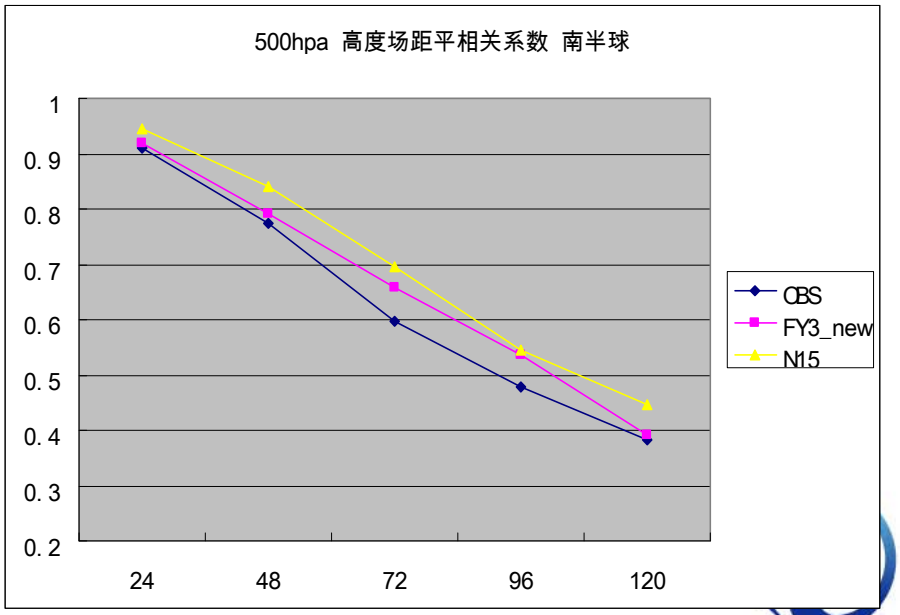
Exp1：**TEMP**

Exp2：TEMP + MWTS /FY-3。

Exp3：**TEMP** + AMSU-A/NOAA15。

国家气象中心
NATIONAL METEOROLOGICAL CENTER





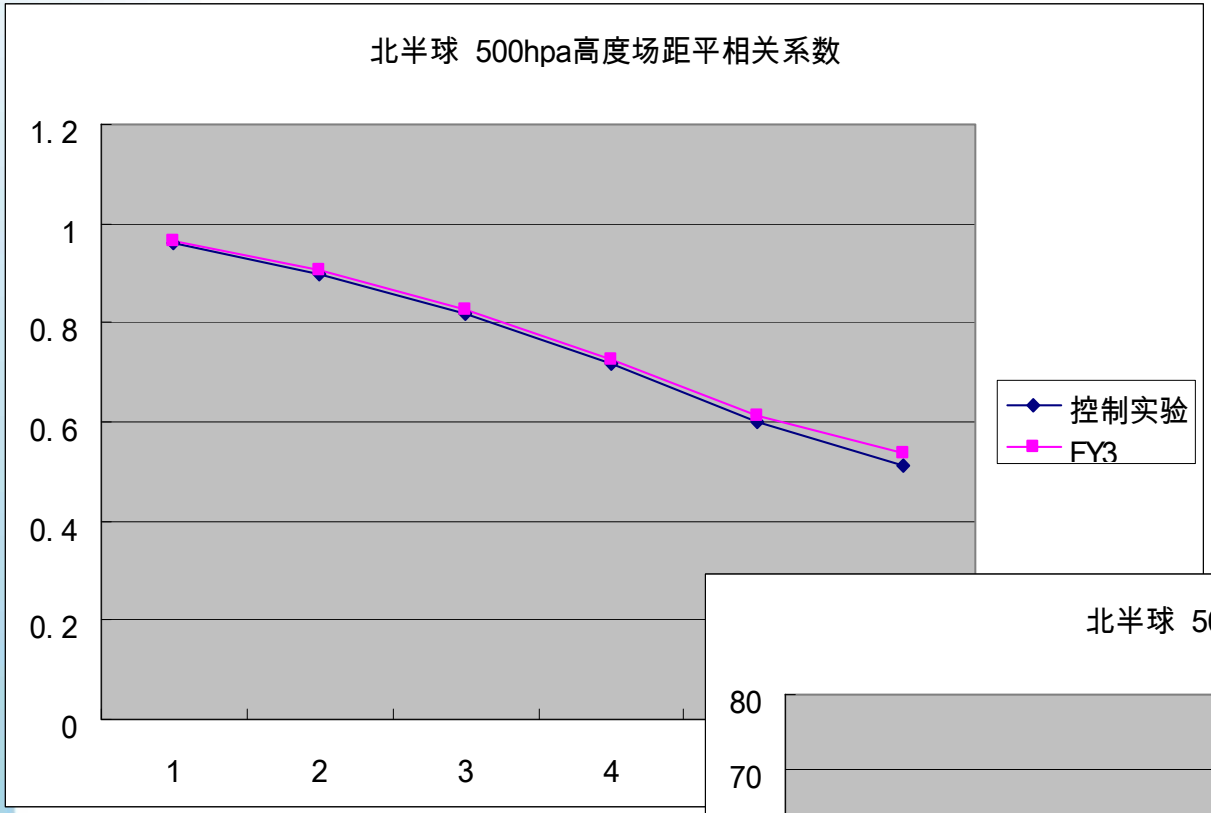
Forecast Impact experiments (2)

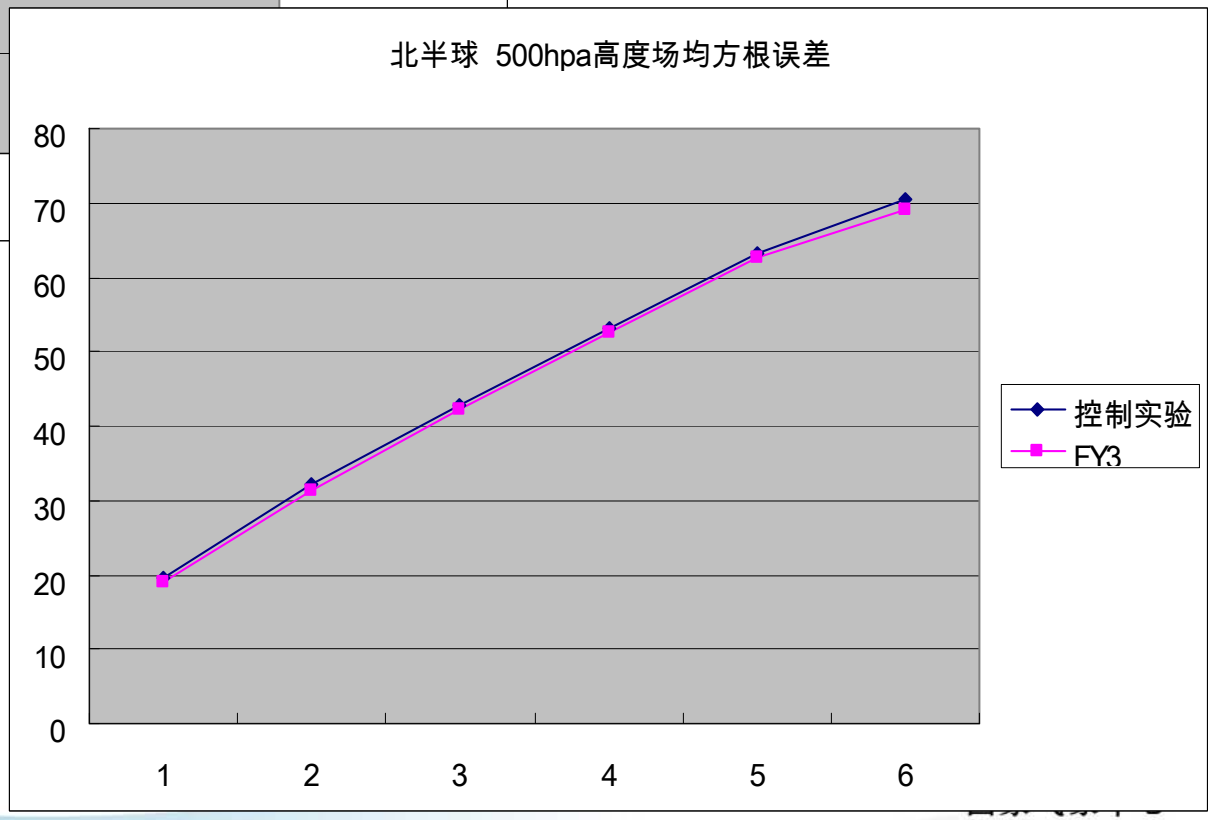
- Date: 20090701-0820
- Contl-exp：

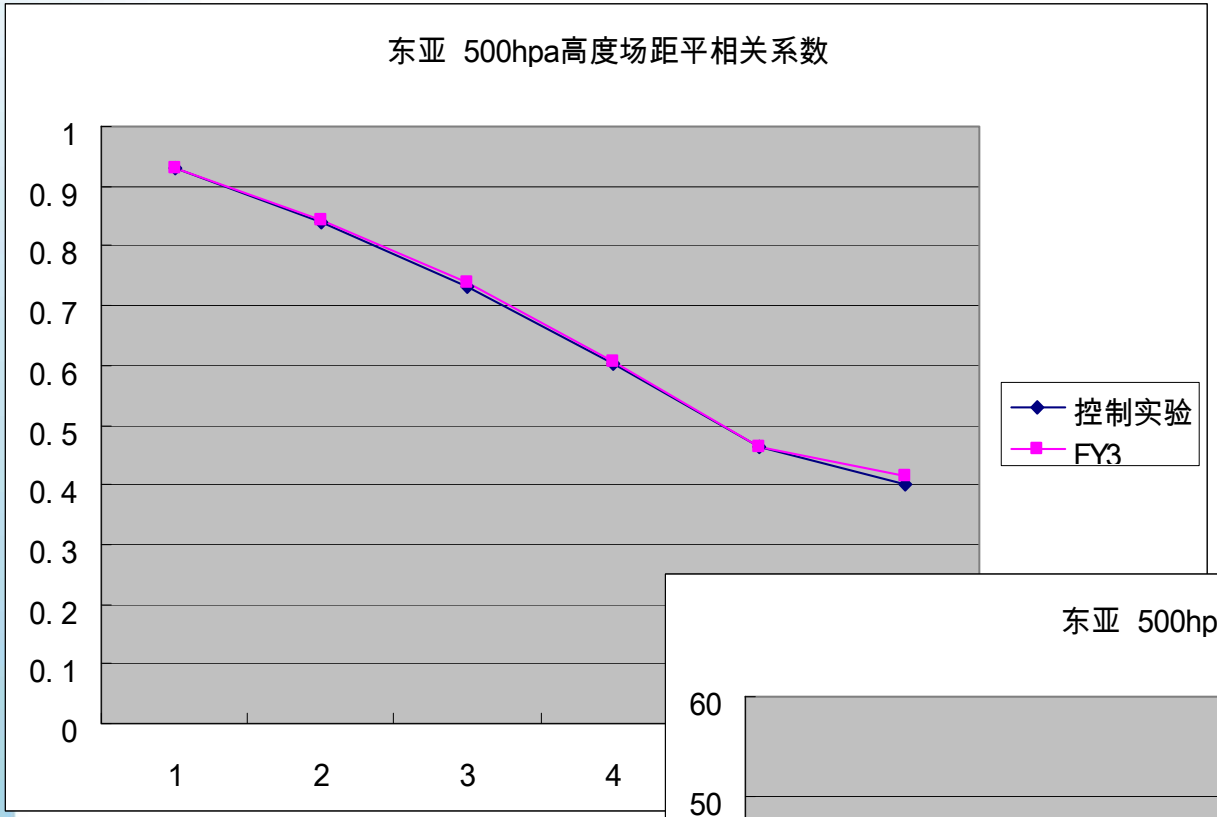
  temp+synop+ships+airep+satob+noaa15a/16a/16b/17b
- FY3-exp:

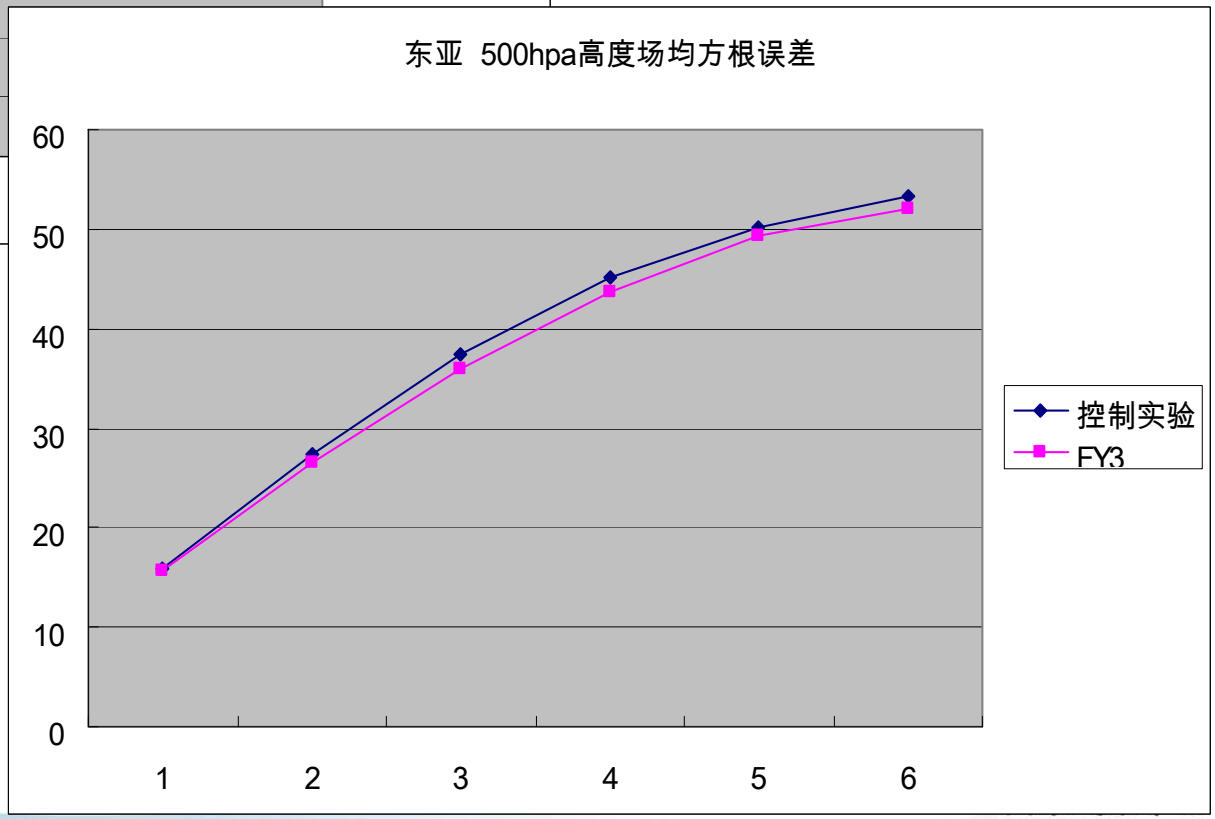
  temp+synop+ships+airep+satob+noaa15a/16a/16b/17b+FY3-mwt

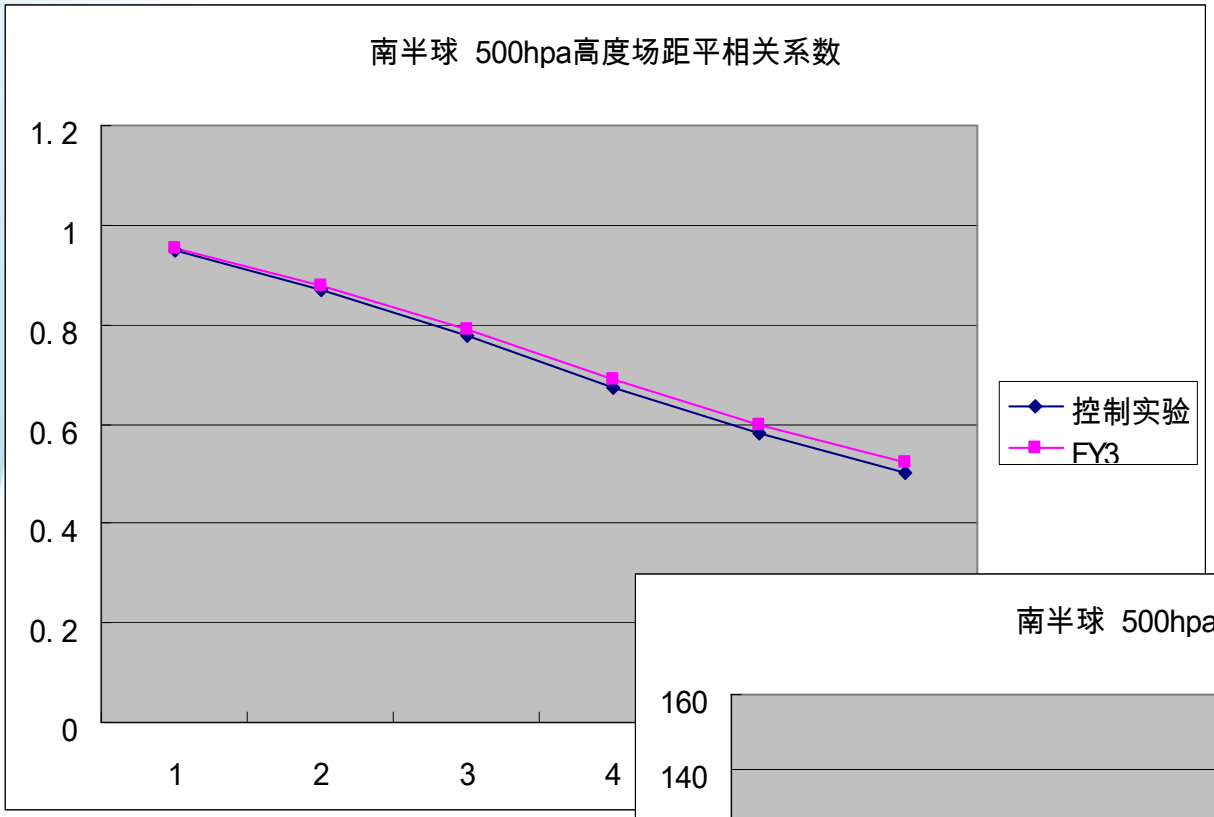
国家气象中心
NATIONAL METEOROLOGICAL CENTER

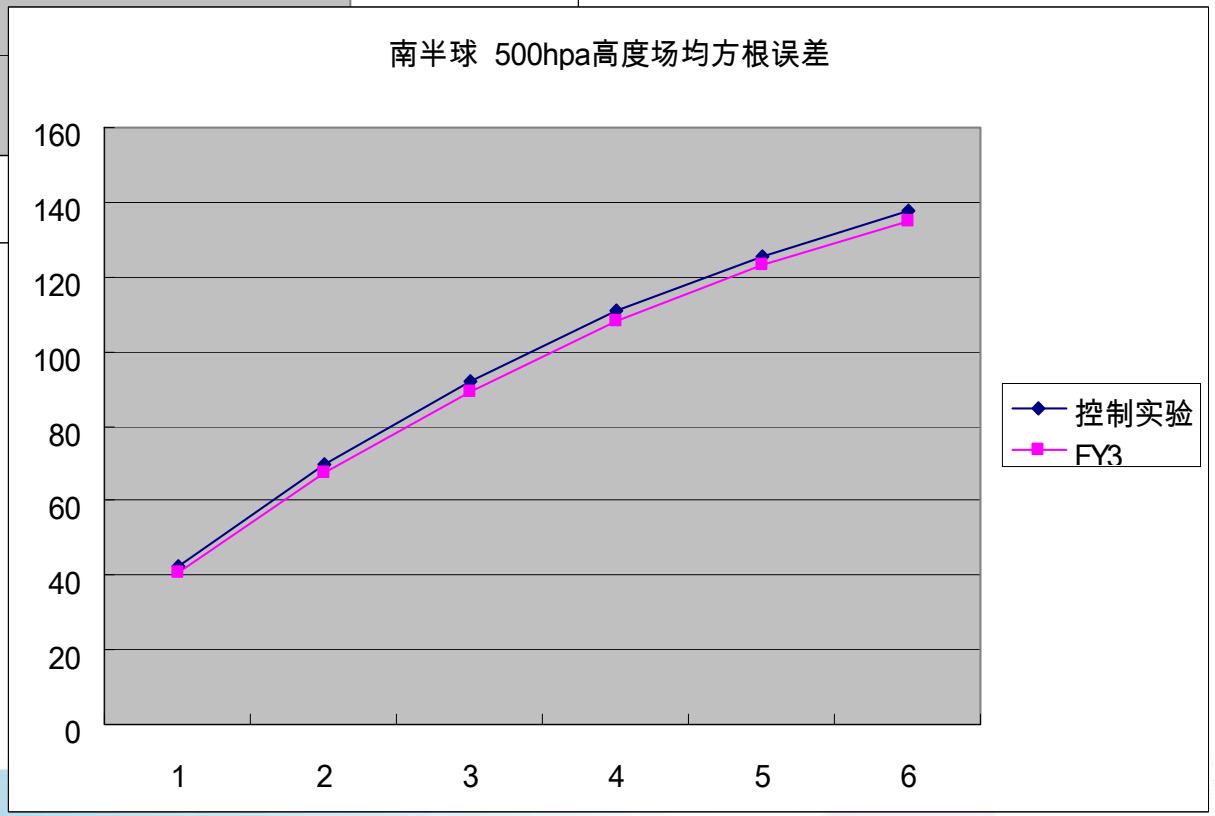

北半球 500hpa高度场距平相关系数
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
控制实验
FY3

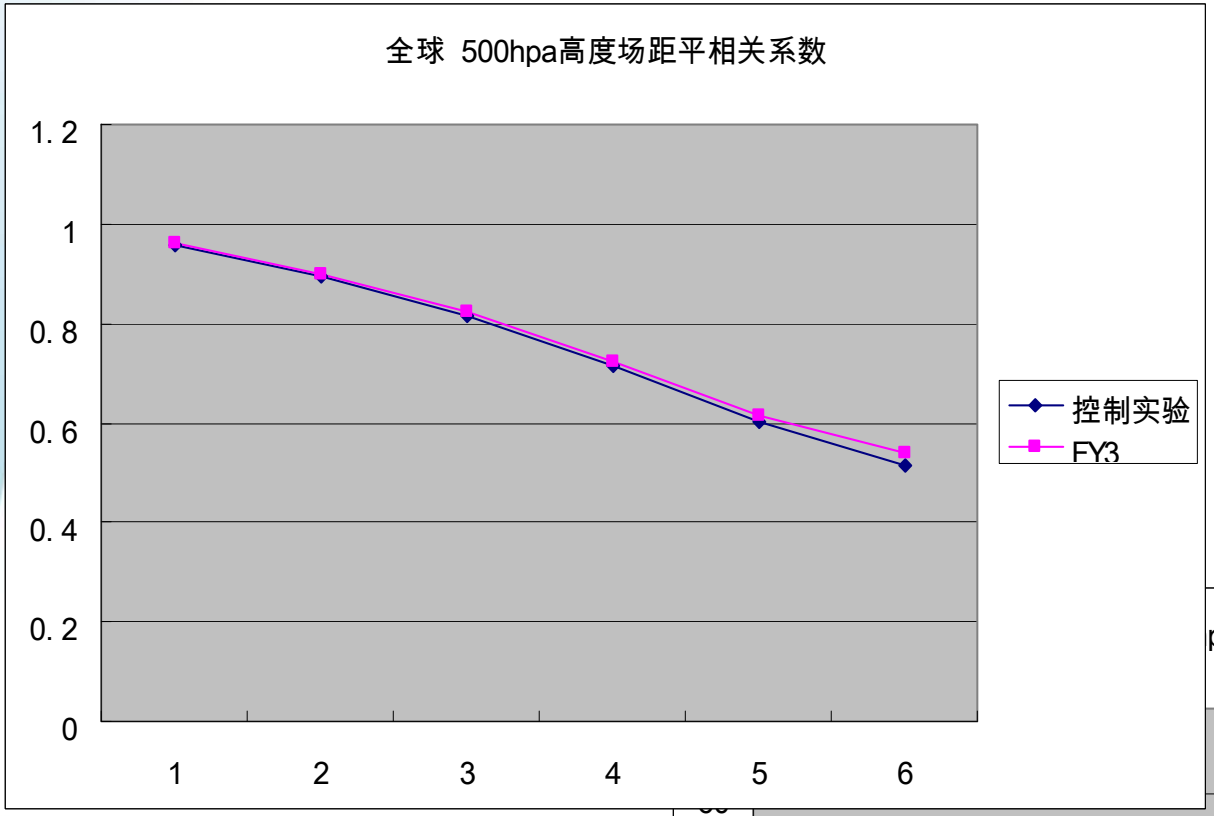

北半球 500hpa高度场均方根误差
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
控制实验
FY3

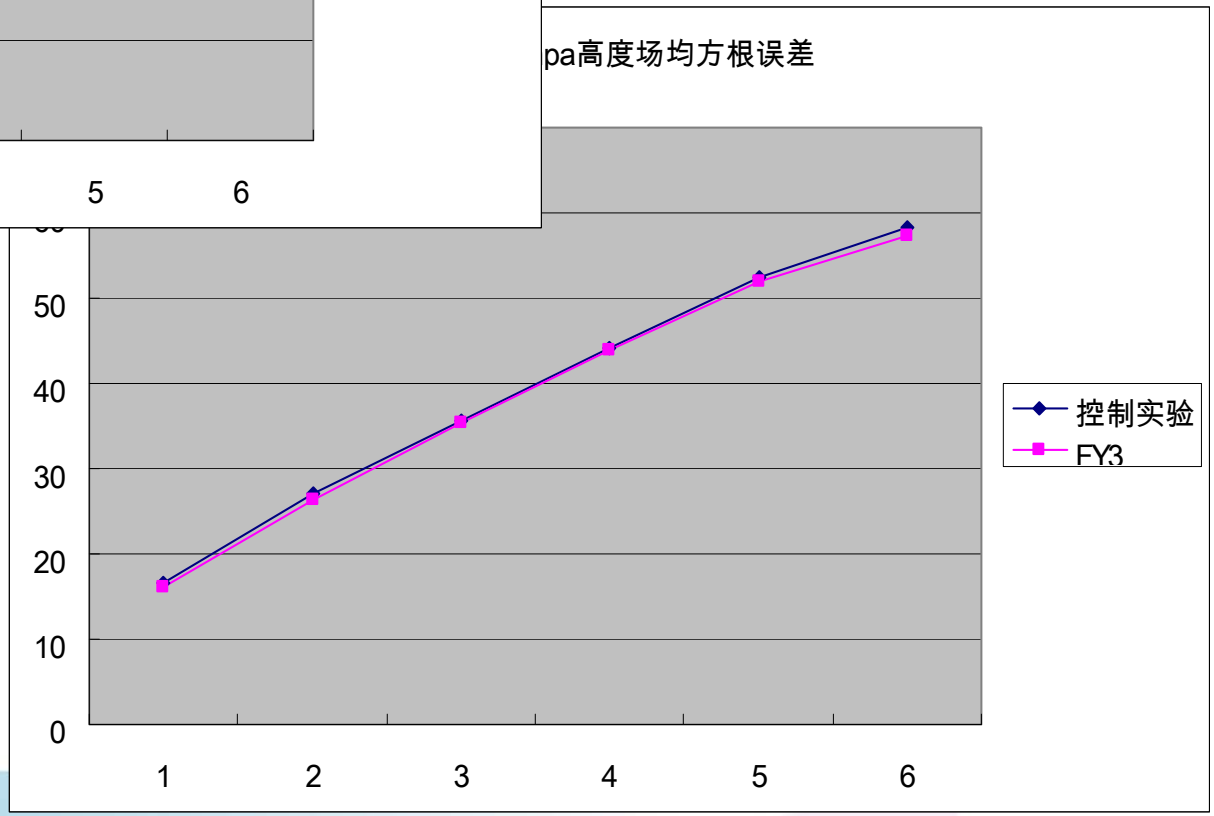

东亚 500hpa高度场距平相关系数
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
控制实验
FY3

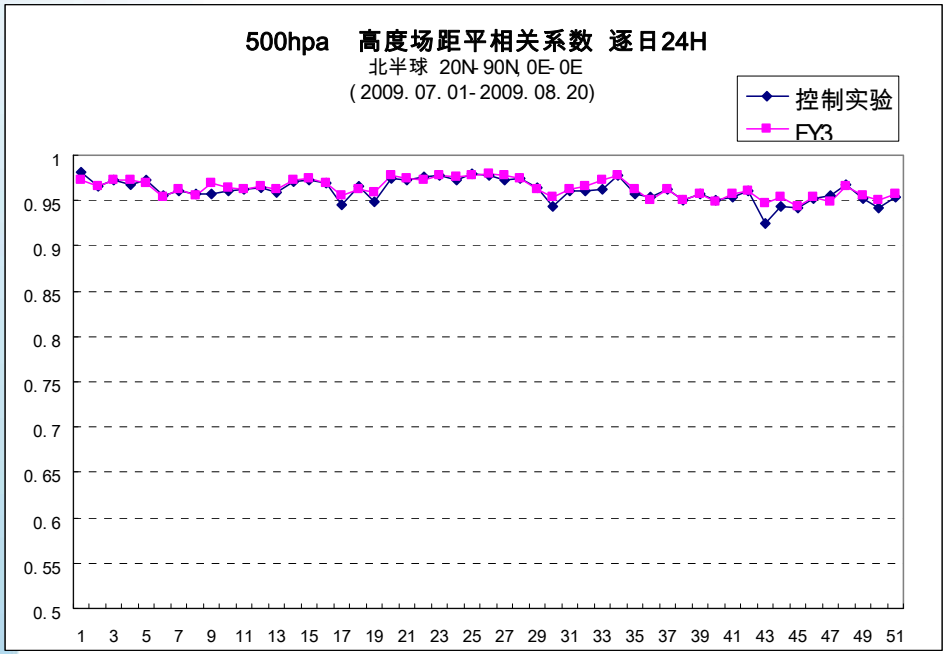

东亚 500hpa高度场均方根误差
60
50
40
30
20
10
0
1
2
3
4
5
6
控制实验
FY3

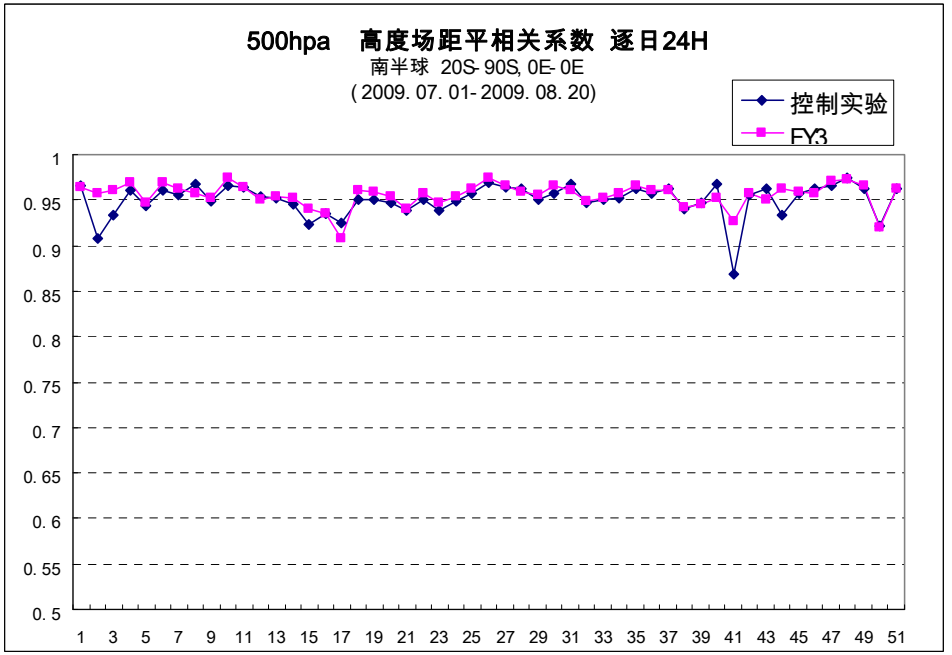

南半球 500hpa高度场距平相关系数
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
控制实验
FY3

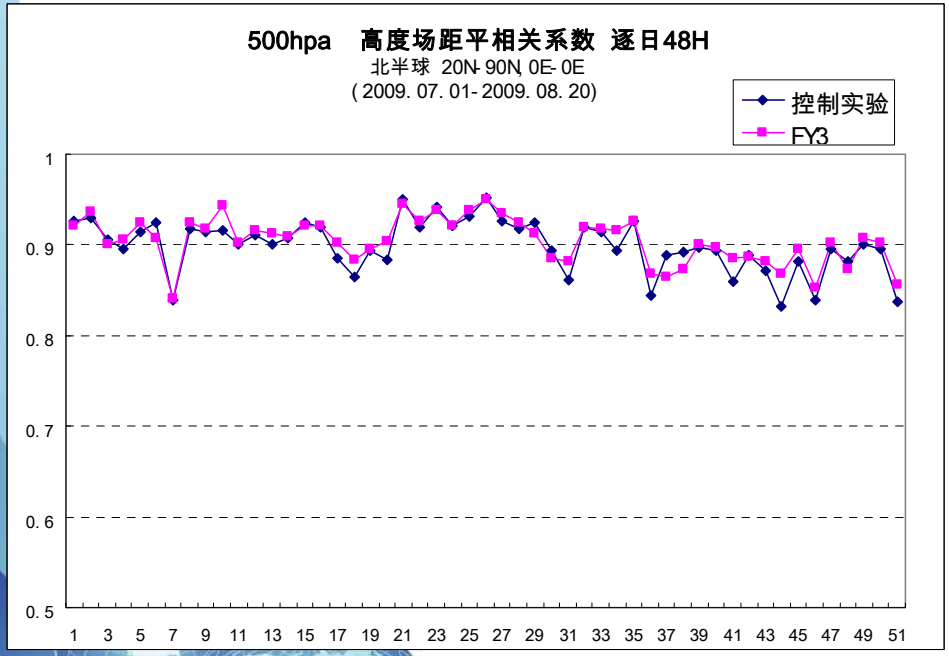

南半球 500hpa高度场均方根误差
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
控制实验
FY3

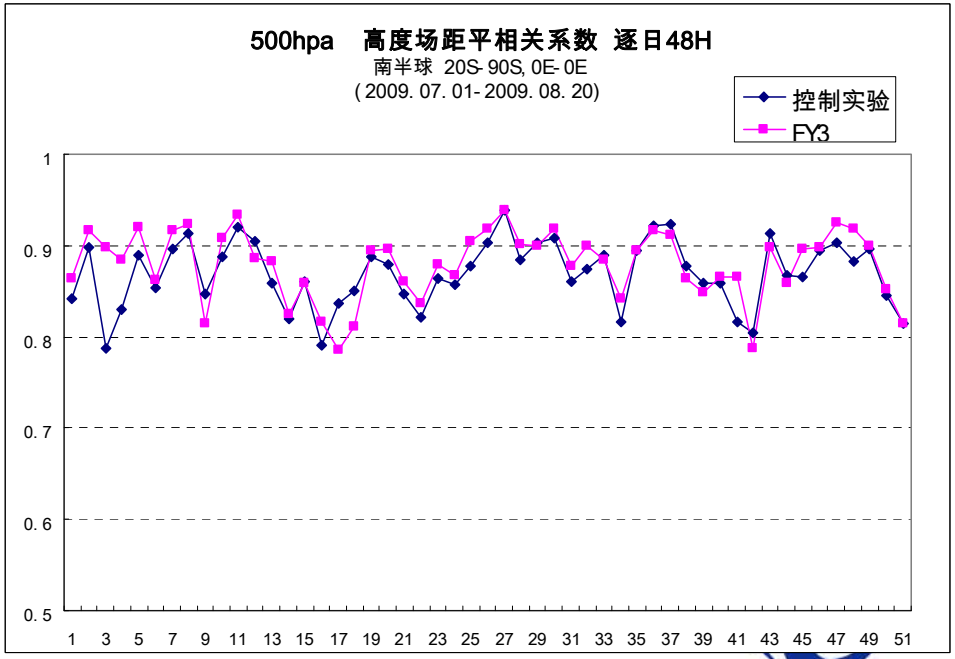

全球 500hpa高度场距平相关系数
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
控制实验
FY3

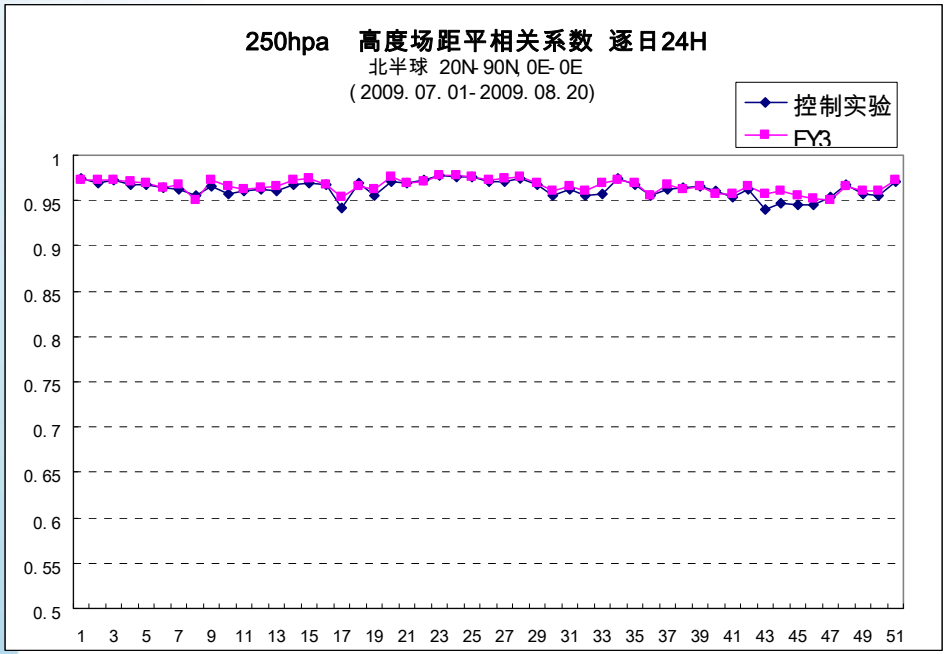

pa高度场均方根误差
50
40
30
20
10
0
1
2
3
4
5
6
控制实验
FY3

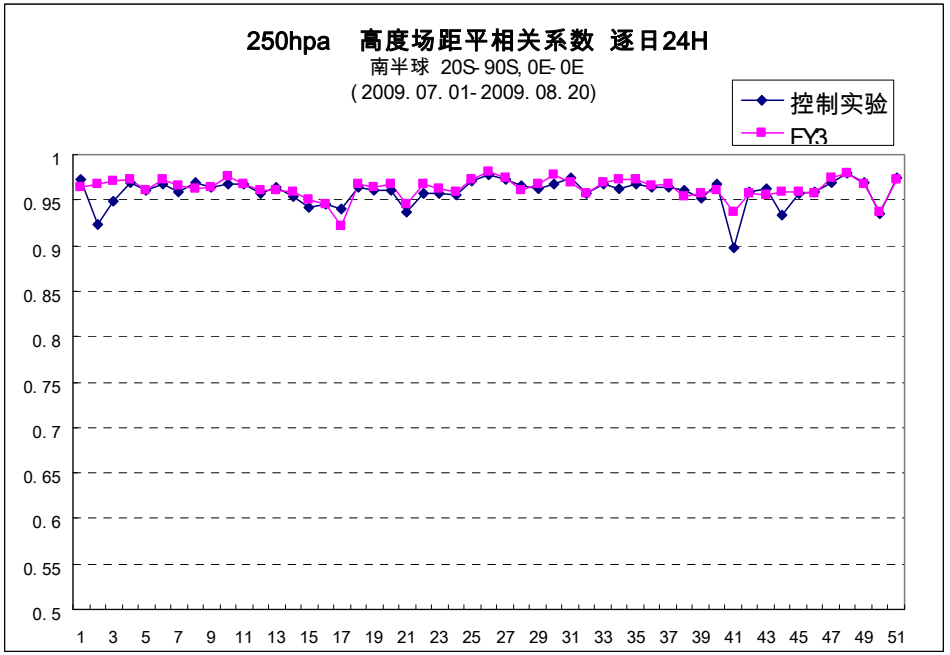

500hpa 高度场距平相关系数 逐日24H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

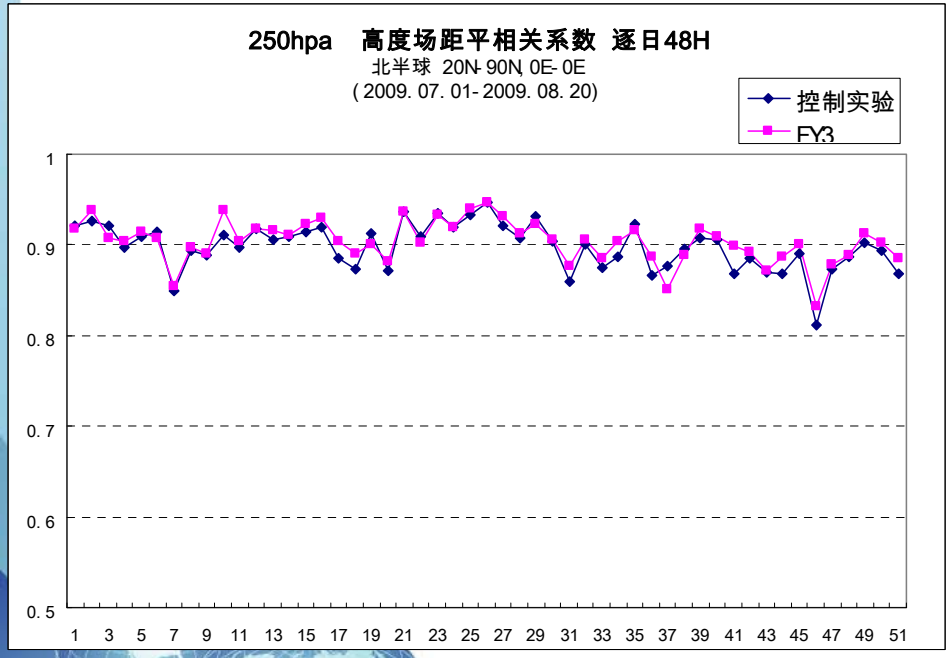

500hpa 高度场距平相关系数 逐日24H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

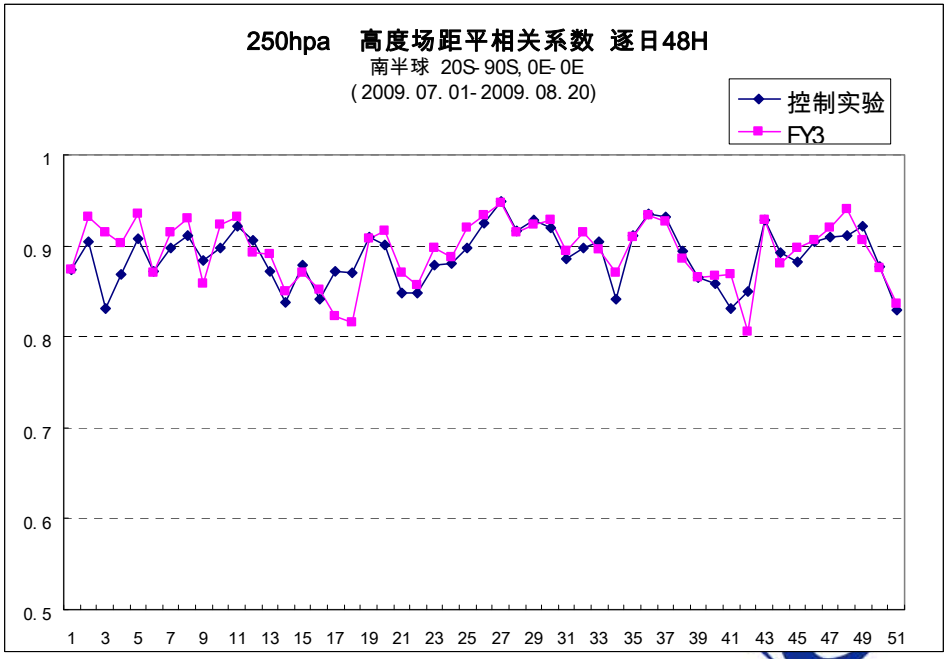

500hpa 高度场距平相关系数 逐日48H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

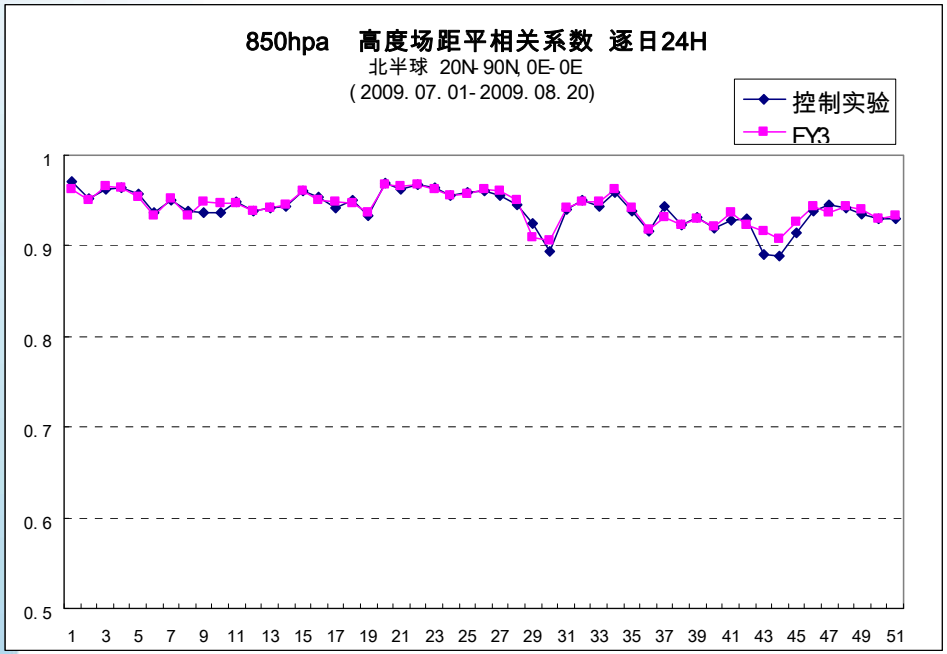

500hpa 高度场距平相关系数 逐日48H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

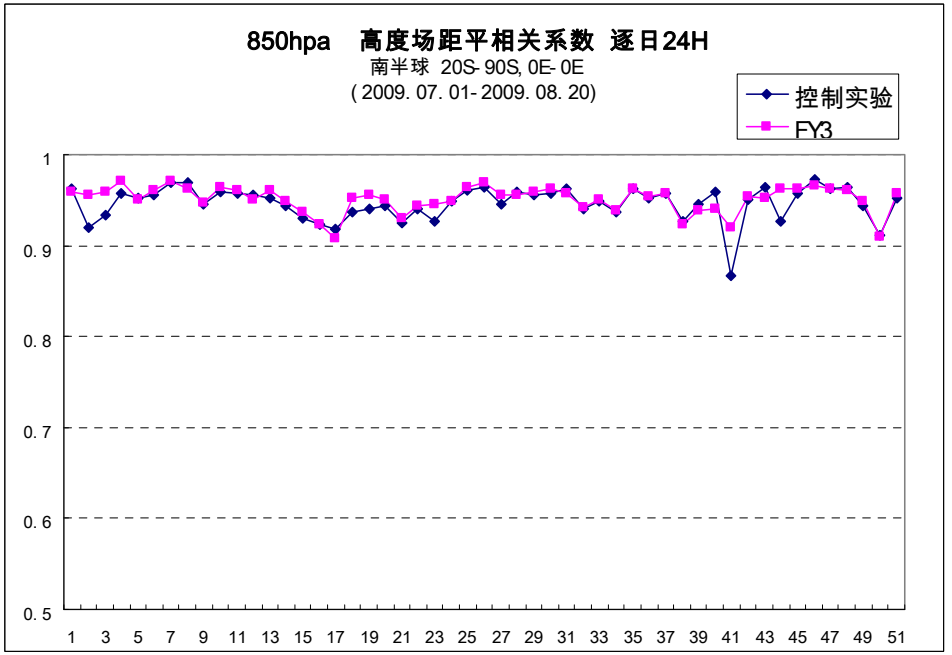

250hpa 高度场距平相关系数 逐日24H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

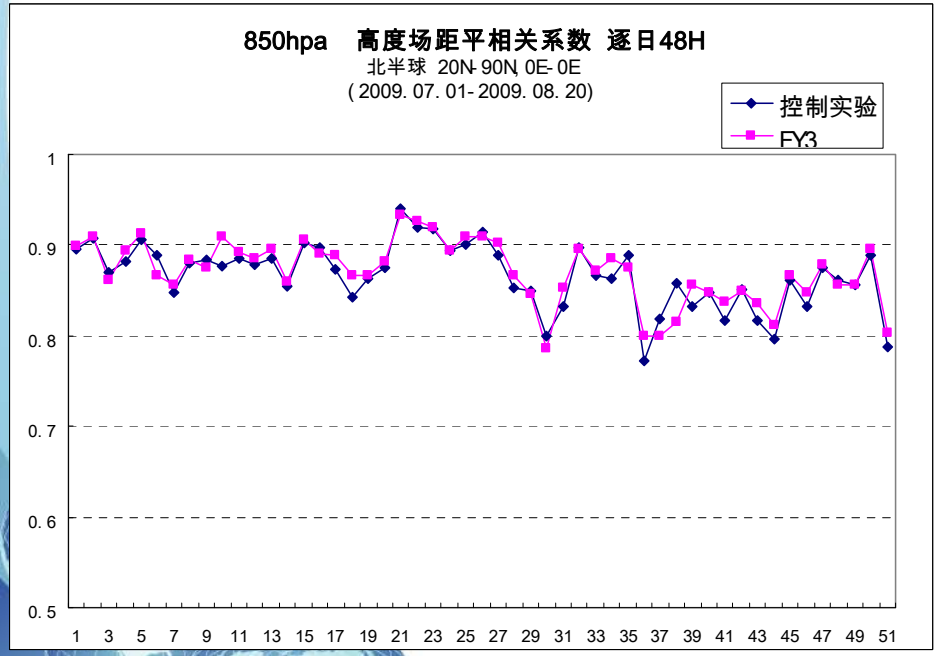

250hpa 高度场距平相关系数 逐日24H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

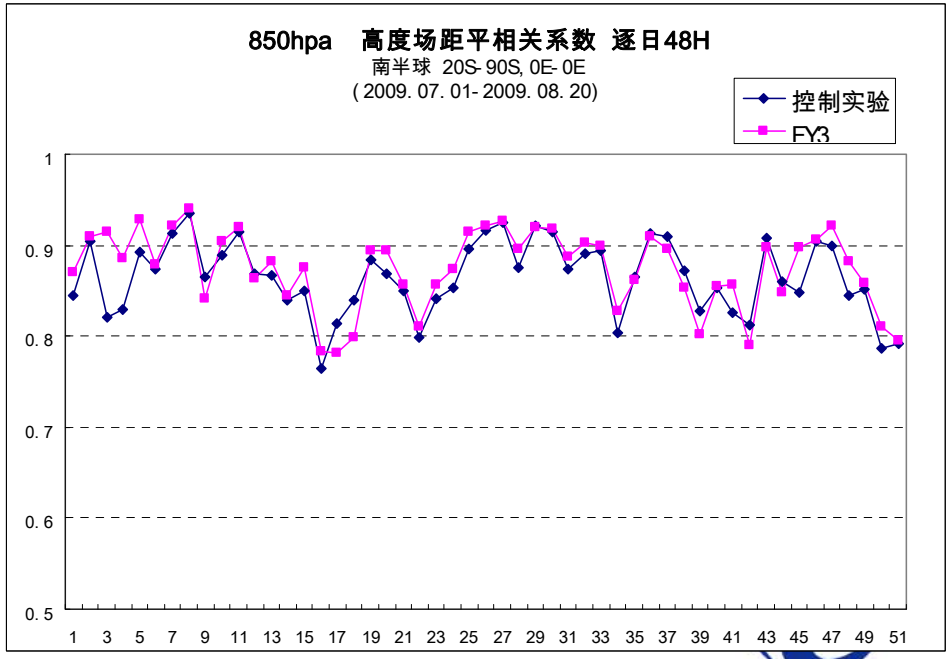

250hpa 高度场距平相关系数 逐日48H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


250hpa 高度场距平相关系数 逐日48H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


850hpa 高度场距平相关系数 逐日24H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


850hpa 高度场距平相关系数 逐日24H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


850hpa 高度场距平相关系数 逐日48H
北半球 20N-90N, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51


850hpa 高度场距平相关系数 逐日48H
南半球 20S-90S, 0E-0E
(2009.07.01-2009.08.20)
控制实验
FY3
1
0.9
0.8
0.7
0.6
0.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51

Outline

- FengYun series satellite
- Analysis & Forecast Model: GRAPES
- FY-3/MWTS radiances assimilation
- FY-2 AMV assimilation
- Summary

国家气象中心
NATIONAL METEOROLOGICAL CENTER

Atmospheric Motion Vectors (AMV)

- Analysis: SSI
- Forecast: T213
- Experiment：

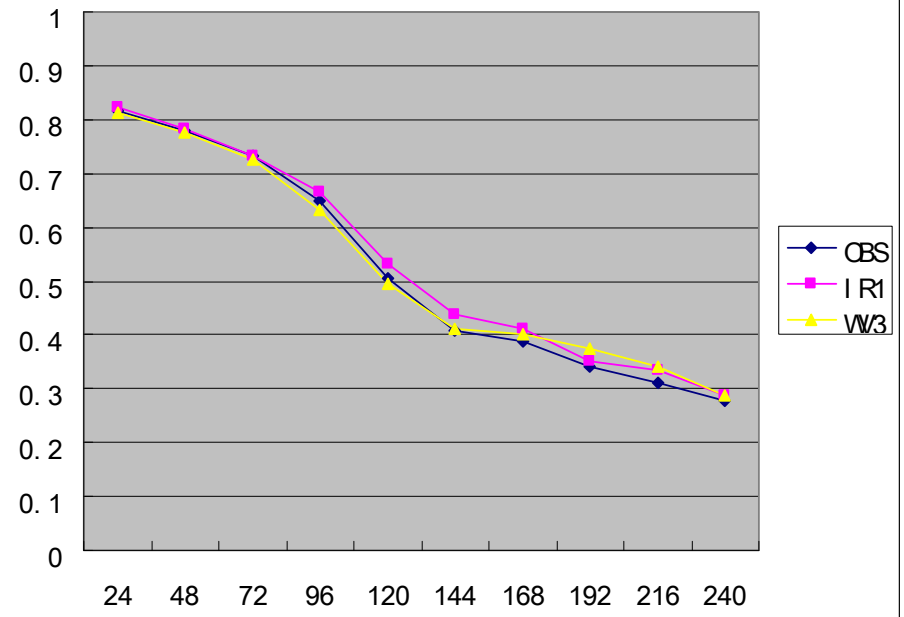
  OBS：temp+synop+ships+airep

  IR1　OBS+FY-2 IR AMV

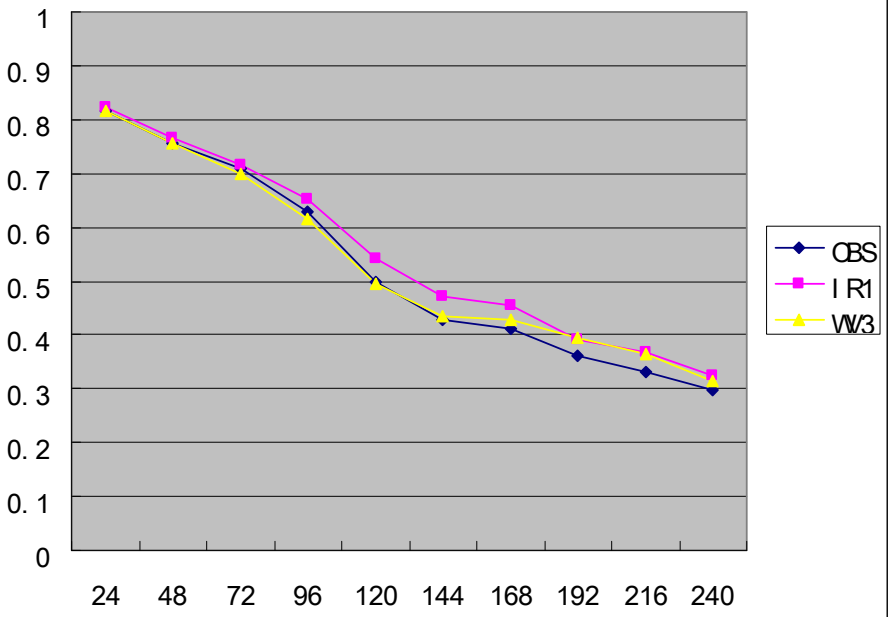
  WV3 OBS+FY-2 Moisture AMV
- Date：20080701-0730

国家气象中心
NATIONAL METEOROLOGICAL CENTER

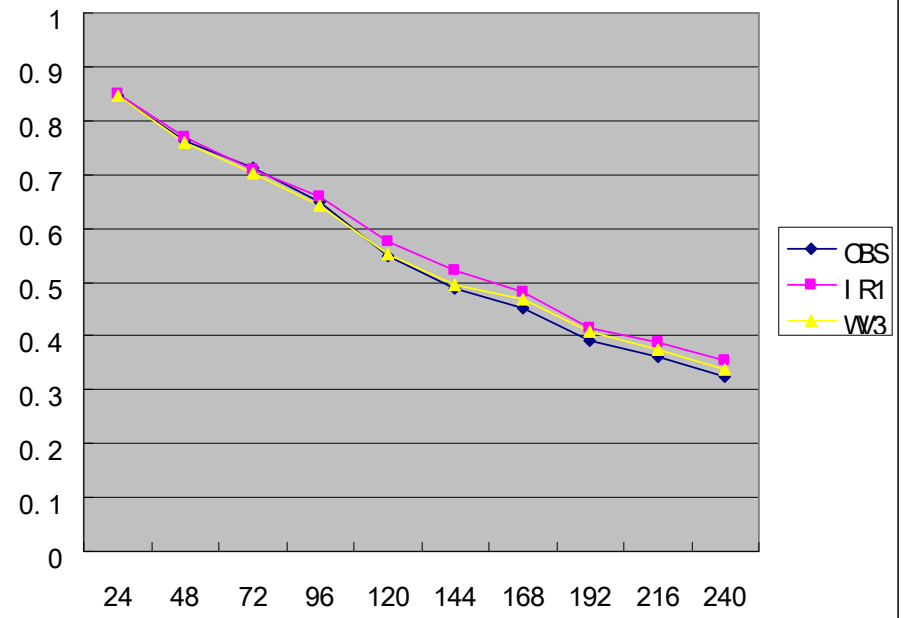
500hpa 高度场距平相关系数 全球



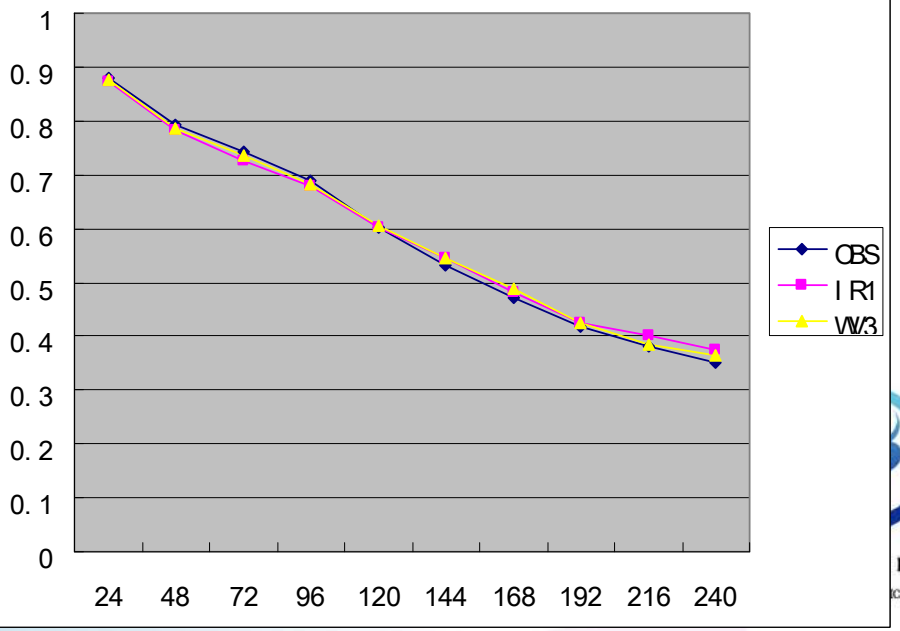
400hpa 高度场距平相关系数 全球



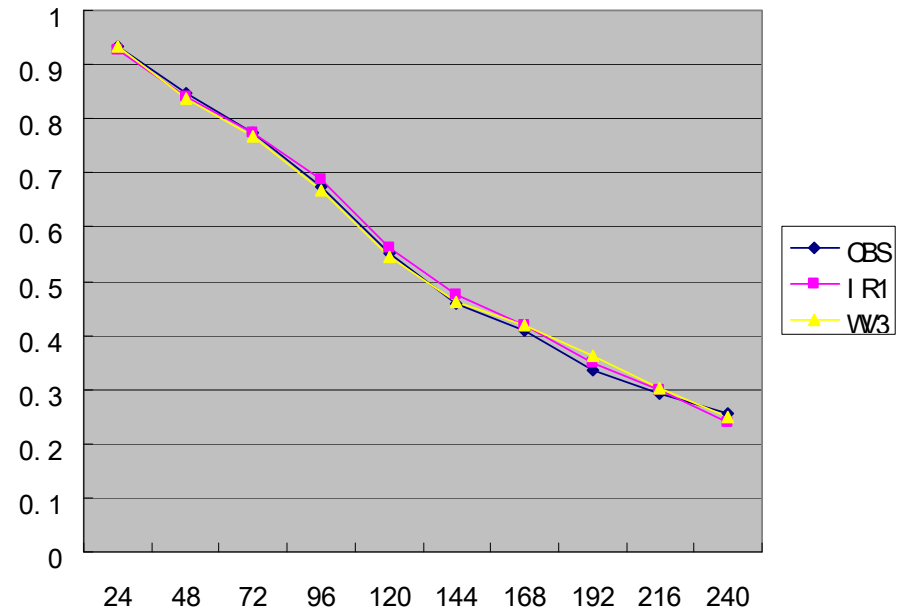
300hpa 高度场距平相关系数 全球



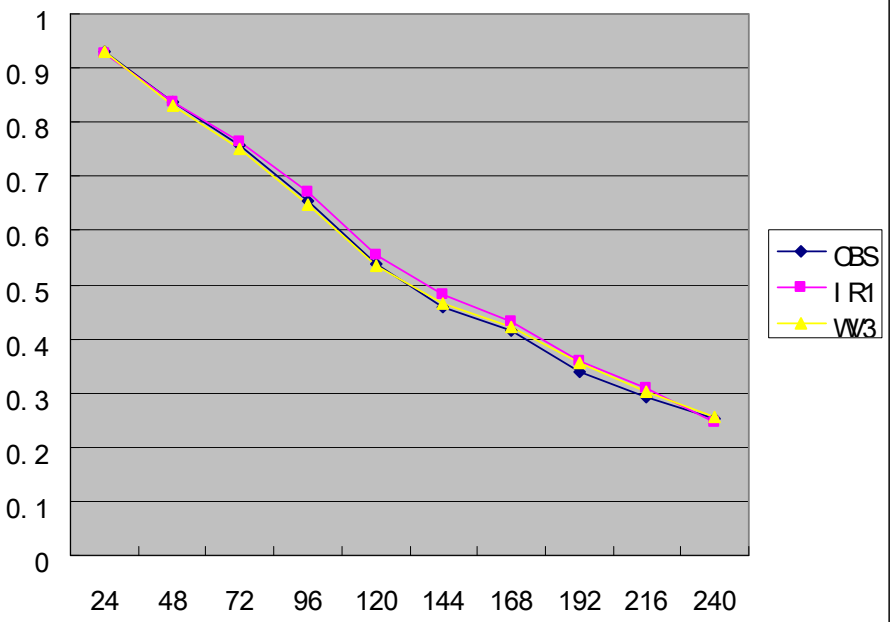
200hpa 高度场距平相关系数 全球



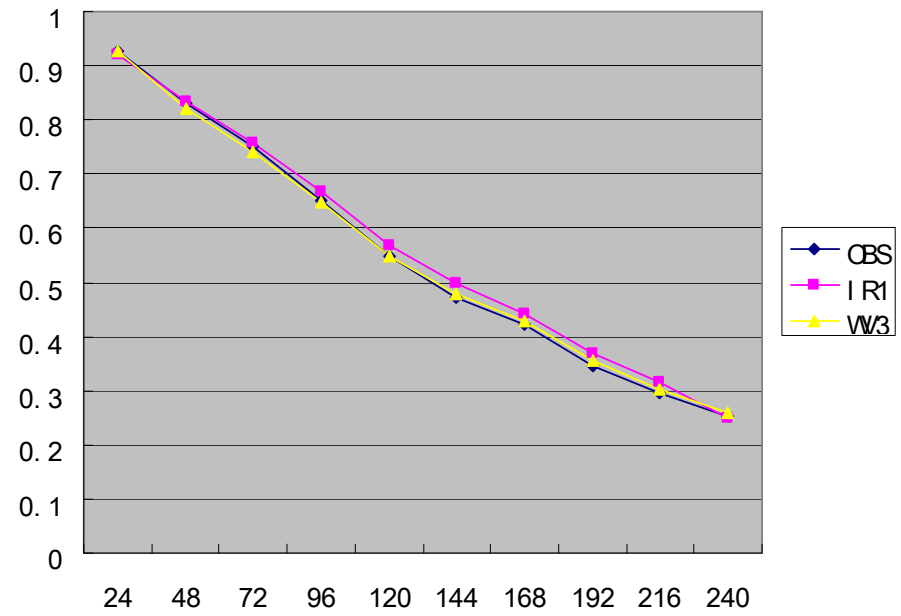
500hpa 高度场距平相关系数 北半球



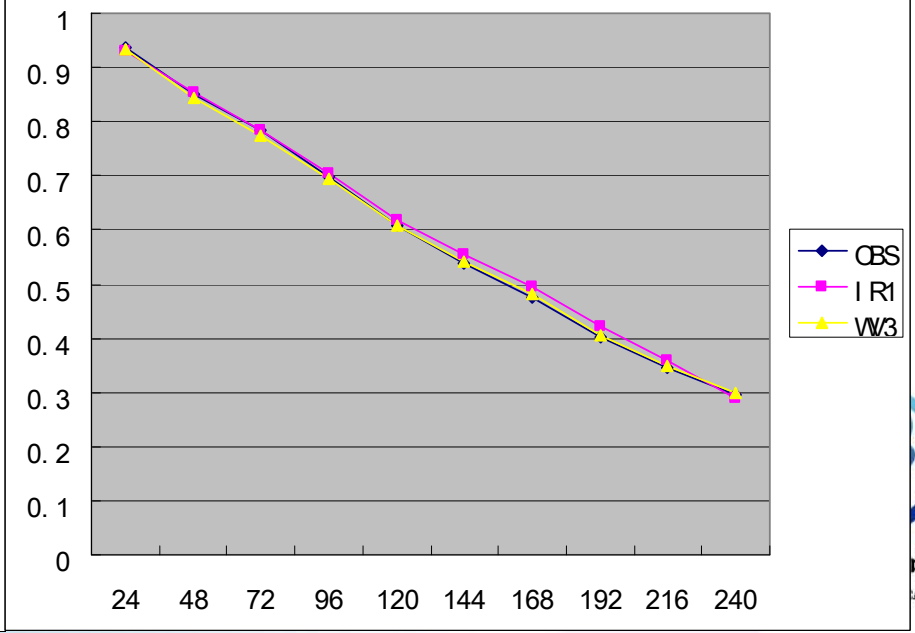
400hpa 高度场距平相关系数 北半球



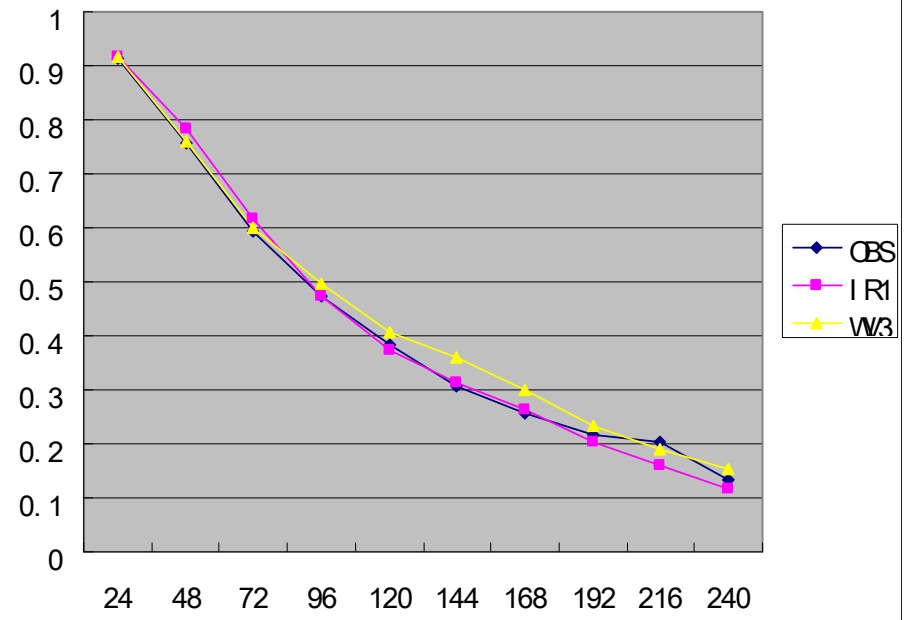
300hpa 高度场距平相关系数 北半球



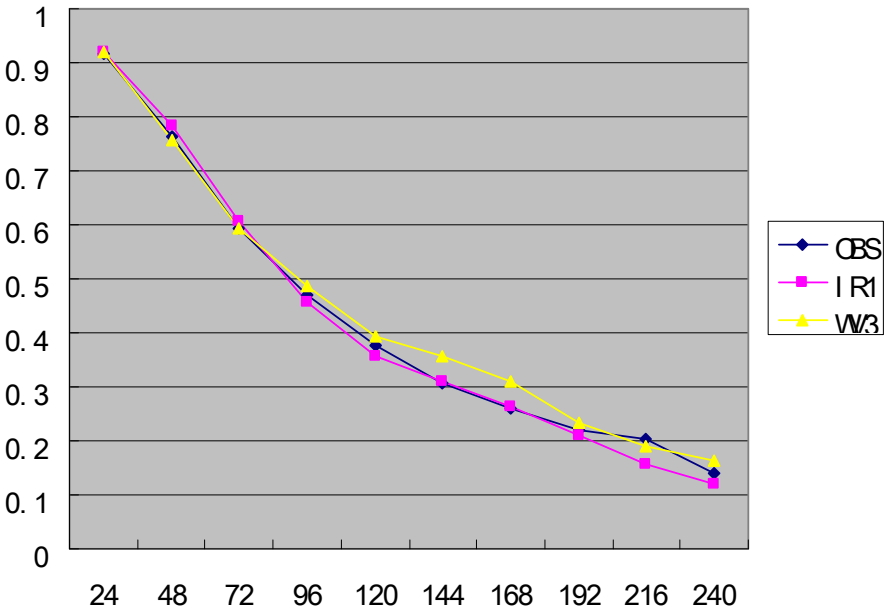
200hpa 高度场距平相关系数 北半球



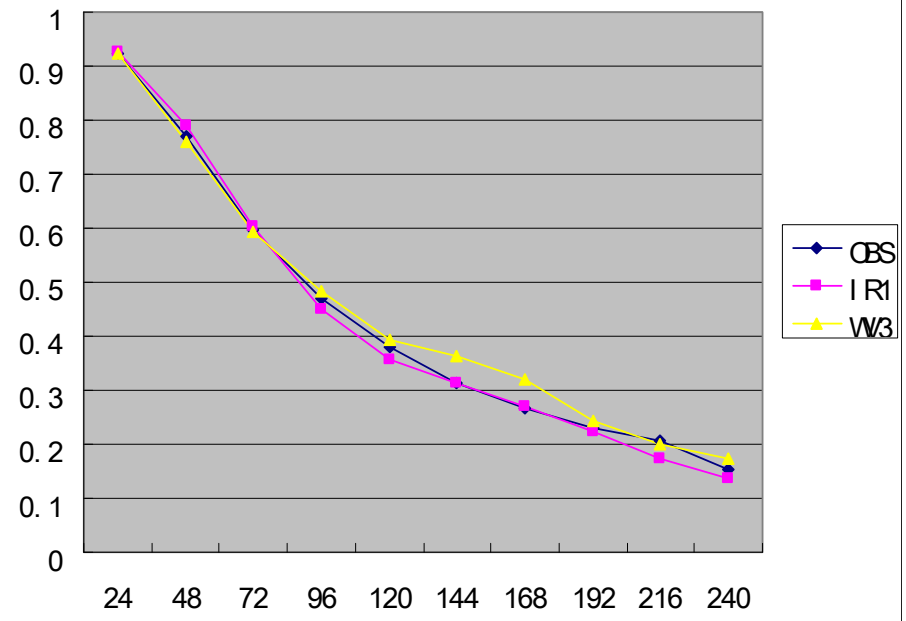
500hpa 高度场距平相关系数 南半球



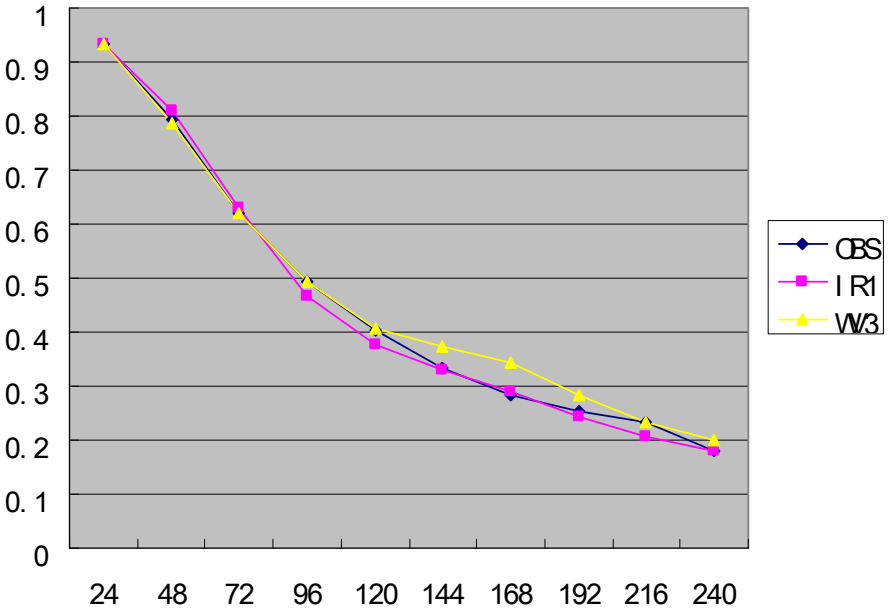
400hpa 高度场距平相关系数 南半球



300hpa 高度场距平相关系数 南半球

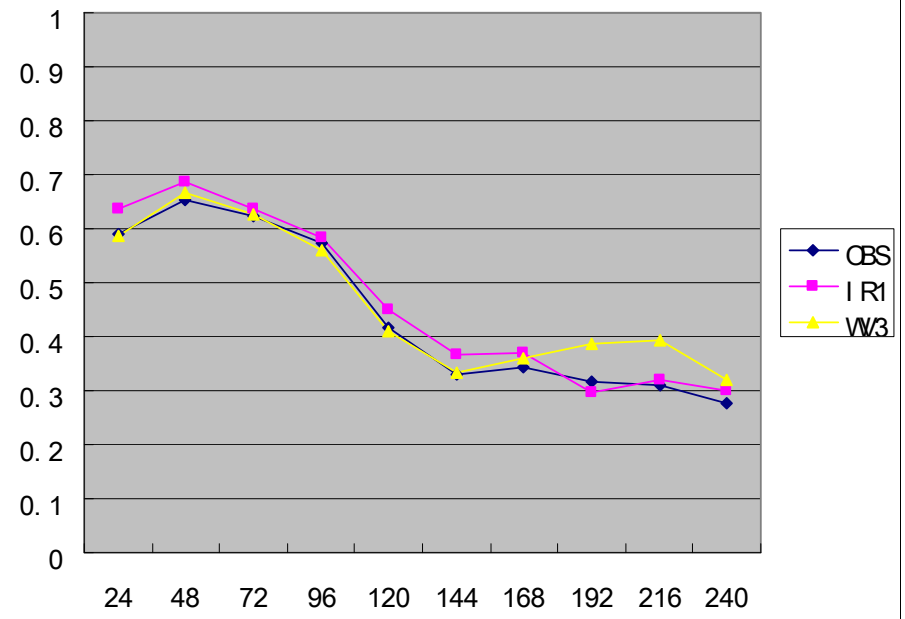


200hpa 高度场距平相关系数 南半球

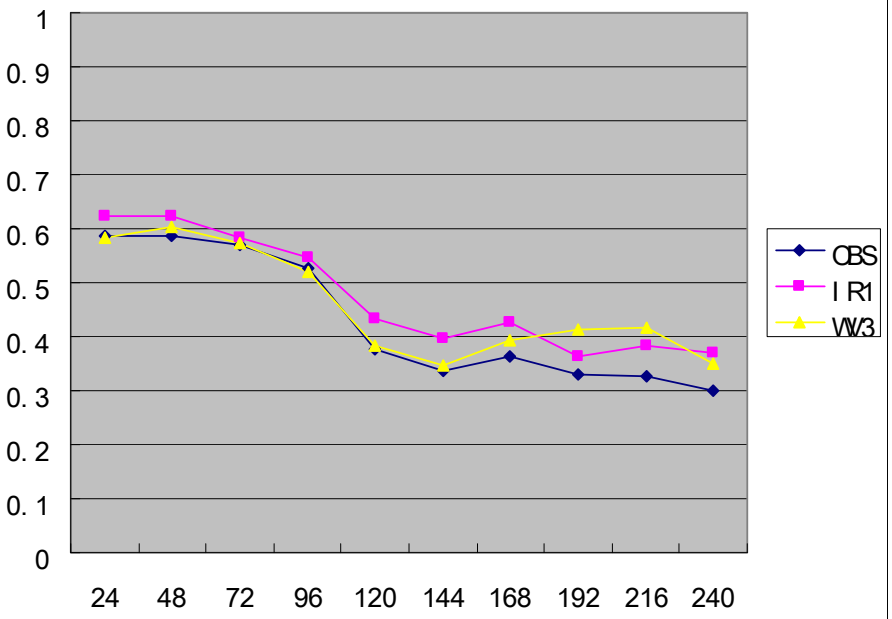


中心
AL CENTER

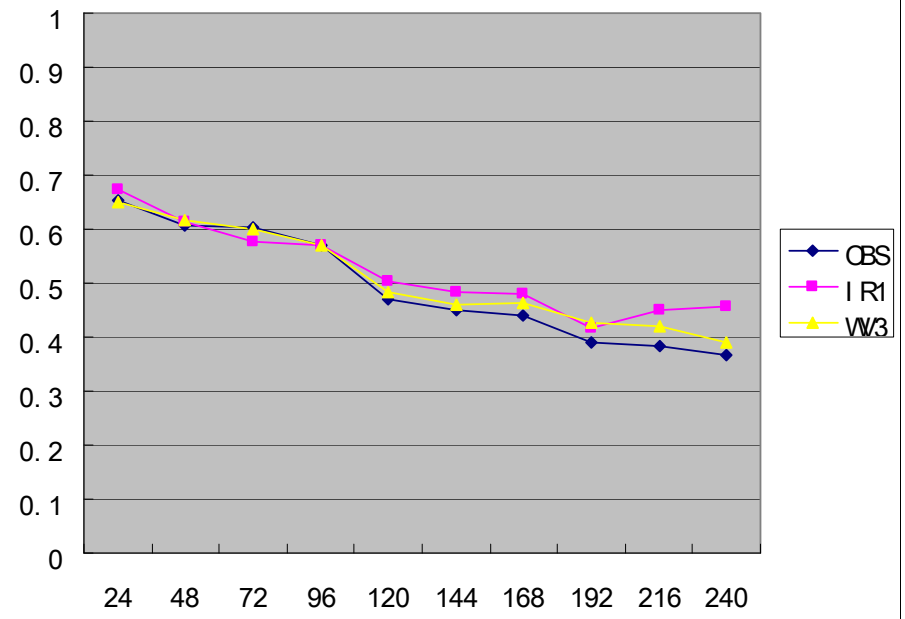
500hpa 高度场距平相关系数 热带



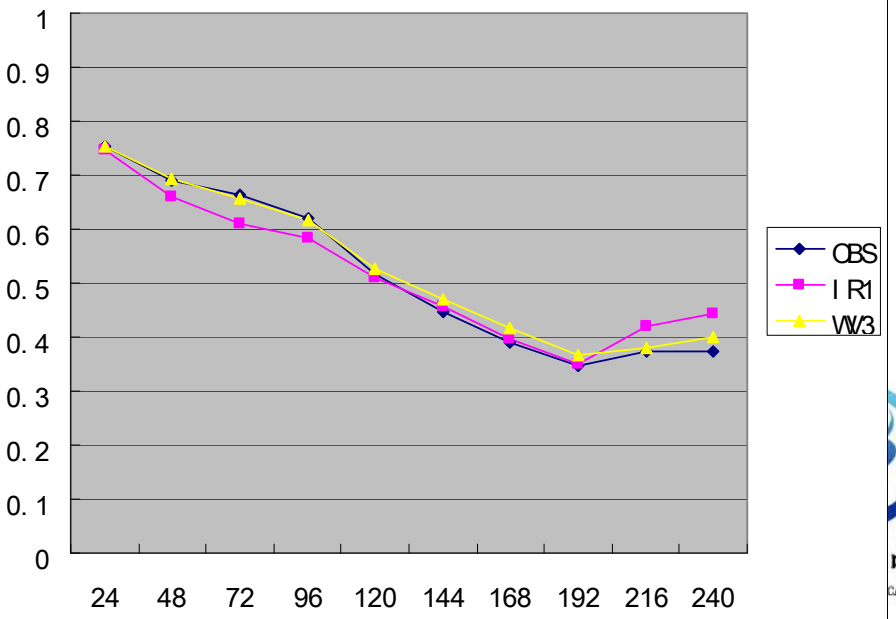
400hpa 高度场距平相关系数 热带



300hpa 高度场距平相关系数 热带

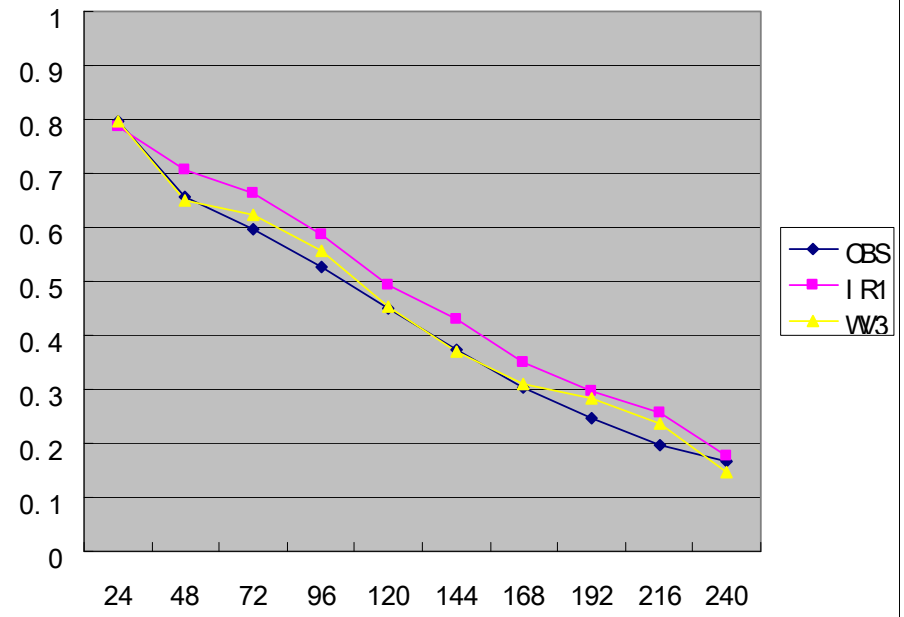


200hpa 高度场距平相关系数 热带

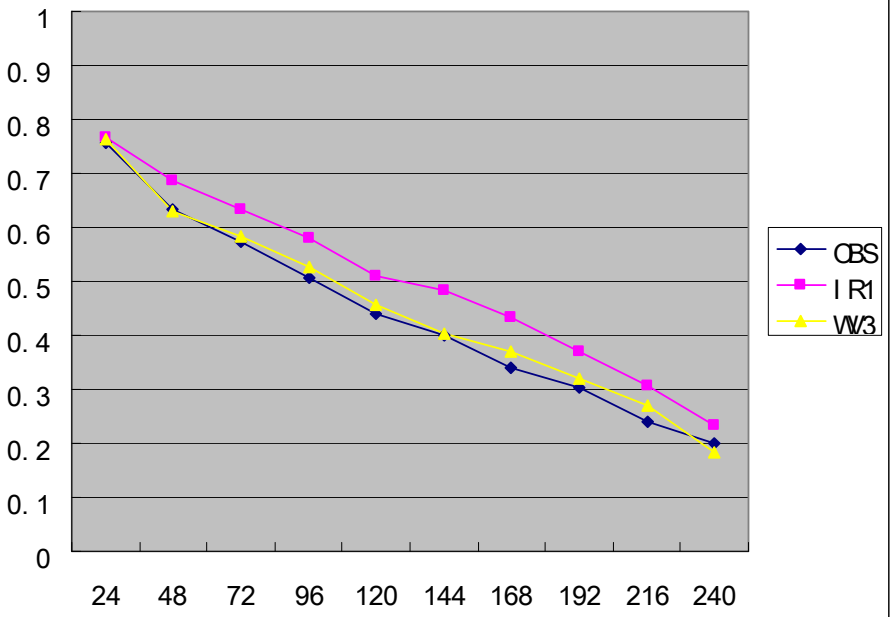


中心
CAL CENTER

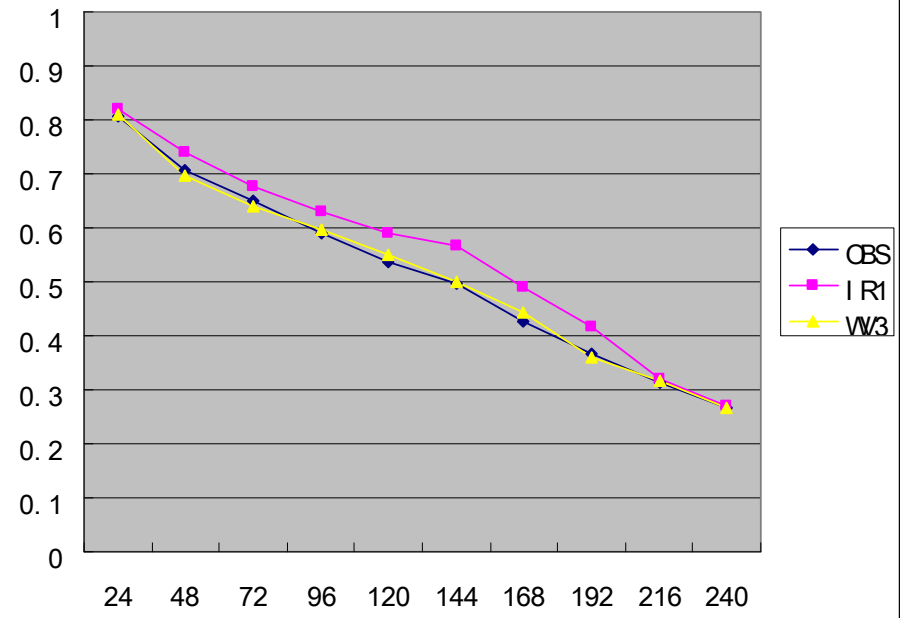
500hpa 高度场距平相关系数 亚洲



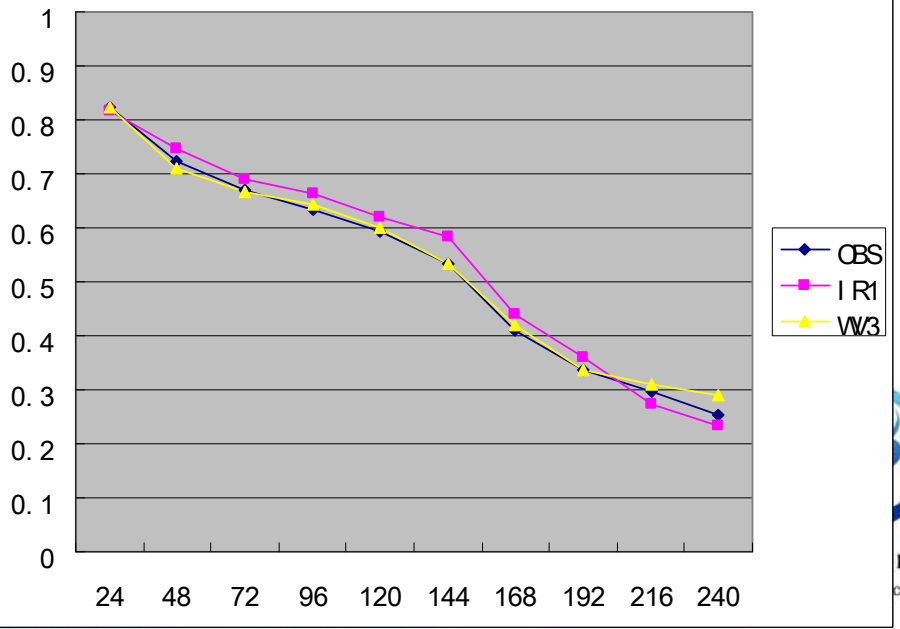
400hpa 高度场距平相关系数 亚洲



300hpa 高度场距平相关系数 亚洲



200hpa 高度场距平相关系数 亚洲



Summary

- FY3A data (MWTS, MWHS) have been successfully assimilated in GRAPES.
- The assimilation experiments were conducted. The experiments show some positive impact and also indicate the data are usable.
- FY-2C AMV show slight positive impact.

Thanks!

国家气象中心
NATIONAL METEOROLOGICAL CENTER